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* * * * *

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This Month's Cover presents a very unusual view of the United Electric Company's Sherman Creek Plant. The photographer was fortunate in obtaining this picture just as the sun was setting and when the cloud formation was particularly beautiful.

MECHANICAL ENGINEERING

Volume 50 March, 1928 No. 3

America's Industrial Future

By DEXTER S. KIMBALL,[1] ITHACA, N. Y.

D. S. Kimball

THE most significant phenomenon of recent times has been the rise of the United States to a dominating position industrially, financially, and consequently politically. Census figures indicate that our national wealth is approaching $400,000,000,000 and that our national income is approaching $90,000,000,000. These are amazing sums of money. No such wealth has ever been acquired by any people, and at no time or place in the history of the race has the level of existence been so high. Most remarkable of all is the short time in which this vast amount of wealth has been accumulated, and having in mind that these totals are increasing at a rapid rate it is interesting to speculate as to what the future holds for us.

Whence comes this great wealth? Of course there are many factors that have influenced this result. Natural resources, an inventive people with highly developed manufacturing ability, a large native population with free internal trade, a willingness to produce upon the part of the workers, and a willingness to pay upon the part of the employers have all been important factors in making our civilization what it is. Many trades and callings have contributed their share in the result, and all of them are important. If I were asked, however, to name the three most important callings I should name Agriculture, Preventive Medicine, and Engineering, using the last term in its broadest sense to include the applications of science to the problem of productive industry. These fields of endeavor are more or less mutually interdependent. The Panama Canal, for instance, was made possible through engineering and preventive medicine. Great cities like New York are habitable largely through the same agencies, and the relation between agriculture and manufacturing needs no explanation. The speaker is not competent to discuss the growth and possibilities of agriculture or medicine, and this address has therefore to do with certain features of engineering and its derivative, manufacturing.

Engineering, of course, is as old as civilized man himself. It has made itself manifest principally along three lines of development, namely, the production of tools for doing work, the development of machines for supplying power to operate these tools, and the making of ways and means for communicating information. Curiously enough, though much thought had been given to these problems by our predecessors during the past centuries, it was not until one hundred and fifty years ago that any considerable progress was made. Since that time the applications of science in these fields have been very rapid and the growth in all lines correspondingly great. Just what the final results will be is hard to estimate. Of themselves these developments are interesting and important, but when it is considered that they also are greatly affecting social, economic, and political thought, the possibilities of future development along each of these lines become matters of greatest importance. It may be interesting, therefore, to review very briefly the progress we have made in these fields.

Progress Made in the Development of the Tools of Industry, Power-Producing Machinery, and in Methods of Communication

It is a far cry indeed to the stone hatchet of our savage forbears, but, relatively speaking, the progress we had made in developing the tools of industry up to the middle of the eighteenth century was quite insignificant. At that time the human race was still earning its living with handicraft tools, and some of these tools were primitive indeed. The demands for new methods and tools that were created by the steam engine and the new textile-manufacturing machinery near the end of the eighteenth century gave a great impetus to the construction of what we now call "machine tools," and the modern lathe, planing machine, boring machine, and drilling machine came into existence. To these in later years were added the milling machine and the grinding machine.

Now these machine tools are of greatest importance since upon them depends the production of all other tools, and the progress we have made in their construction is important since it is a gage of all mechanical development. The first lathe could easily be carried by one man. Today there are lathes that will machine cylinders 14 ft. in diameter and of any desired length. Boring mills that will machine work up to 34 ft. are advertised as a standard product, and the great mill at the Schenectady works of the General Electric Company will handle work up to 60 ft. in diameter. It is interesting to speculate as to the maximum size these basic tools may attain. Apparently they will continue to grow as long as the demand for growth in industrial machinery continues. And this growth, it should be noted, is very rapid. The first locomotive weighed $3^1/_2$ tons, while a modern freight locomotive of the largest type weighs 400 tons. The two cables of the bridge over the Delaware at Philadelphia are each 30 in. in diameter, and already another bridge over the Hudson is projected which will be carried upon four cables each 36 in. in diameter. Illustrations of this kind can be cited without end.

In the development of power-producing machinery the rate of growth is equally rapid. The famous Corliss engine that drove the machinery of the Centennial Exposition of 1876 was rated at 1400 hp. and was considered to be a very large machine. By the end of the century cross-compound Corliss engines of 4000 hp. had been built. In the largest power houses of that period two such engines, one on each end of a shaft, were used to drive a

[1] Dean, College of Engineering, Cornell University. Past-President A.S.M.E.

Presidential Address at the Annual Meeting, Washington, D. C., January 10 and 11, 1928, of the American Engineering Council.

generator placed in the middle of the shaft. These generators were about 30 ft. in diameter and the problems incident to manufacturing them did much to hasten the construction of the large machine tools referred to. The first Curtis steam turbine was of 5000 kw. capacity. Today turbo-generators of 50,000 kw. capacity are quite common, and there are now under construction two turbo-generator sets of 90,000 kw., one of 104,000 kw., and one of 208,000 kw. Again, a few years ago a power house of 1000 kw. capacity was a large installation. Today power houses of 300,000 kw. are not considered unusual, and one such power house at least is laid out in anticipation of a capacity in the near future of 1,000,000 kw. Dr. Fred R. Low has estimated that the total developed horsepower in the United States today is sufficient, if required, to give every man, woman, and child service equivalent to that rendered by 150 slaves, and the power houses of this country are doing more work than could be accomplished by all the able-bodied men in the world working from sunrise till dark. Again one wonders where the end will be, for at present this growth shows no sign of abatement. The latest development in the direction of furnishing ample power to those who till the soil is filled with vast possibilities.

The problem of communication is also as old as man himself. Our native Indians used puffs of smoke, the ancient Greeks and Romans used semaphores and heliographs, and other primitive methods have been used by others. Then out of modern scientific investigation came in rapid succession the telegraph, the telephone, and the radio with all their wonderful efficiency and convenience. These inventions have literally eliminated time and space so far as communication is concerned, and they have accelerated the modern industrial organization to an almost unbelievable degree. When one considers the difference between the old days when the slow letter post was the only way of communicating between, say, Boston and Washington, and our present telephone methods, the thought again recurs—what next? Shall each of us carry around our own portable radio receiver so that we can tune in and listen to the world's happenings? Or, more interesting still, shall we listen to messages from other planets through these mysterious vibrations of the ether? Who can say what the future holds?

One of our greatest problems, therefore, is to bring to the aid of governmental bodies the technical advice and knowledge of our professional groups. This will be no easy matter, for obviously legislative bodies must be free to work out their own solutions. But, nevertheless, it would appear to be logical that if all of the professional groups had some means of expressing themselves nationally they could be of great service. The American Bar Association is such a body, and one that has done much to advance sane legislation. The American Engineering Council is another similar agency that has already amply justified its existence. For it should be remembered that the professional groups all together constitute only a small part of our population. The entire body of technically trained scientists and engineers are but a small handful, relatively speaking. Yet this small handful has revolutionized industry and is now reforming our national habits and our economic and social needs. The methods by which all this has been accomplished are also applicable to the solution of some of these economic and social problems. It remains to be seen how these principles can be utilized to these ends. For if government of the people, by the people, and for the people shall fail us it will not be because of lack of able representatives or of loyalty of the people at large, but because we shall not be able to bring to bear upon these difficult national problems the same kind and degree of technical skill and knowledge that has brought them into being.

Far-Reaching Economic, Social, and Political Changes Brought About by Modern Industrial Developments

Now, as before stated, these developments are important of themselves, but when we consider that they draw in their wake far-reaching economic, social, and political changes, they take on added importance. For good or evil these great industrial changes are reshaping many of our ideas and changing many of our long and firmly held beliefs. It may be of interest to glance briefly at some of these changes.

From the beginning of the modern industrial era it has been firmly held that low cost and low wages were necessarily concomitant. Indeed, this belief is still firmly held by many manufacturers and economists who have not or will not see the full significance of quantity production. The late lamented Fred Taylor was probably the first to point out in a striking manner that this presumption is not necessarily true, but that high wages and low costs are equally if not more logical, and to demonstrate practically the truth of his assertions. And Mr. Ford's striking example of placing all men on a wage of not less than $5 a day when the prevailing average was perhaps $3 was a striking corroboration of Taylor's statements. The reasons back of this changed point of view cannot be reviewed here, but they are found in Taylor's writings and in such classic studies as Alexander's "The Cost of Hiring and Firing Men."

Again, the generations of the past were reared on the philosophy that money was something to be *saved*. Thrift and miserly expenditures were the way to wealth and consequent comfort. Today we see $2,000,000,000 worth of automobiles alone being bought on installment plans that mortgage the earnings of millions of people, and the amount of such debt that is involved in the "deferred payment" of radios, pianos, jewelry, and other more or less ephemeral possessions must be vast indeed. And yet there are not a few economists and staid business men who strongly advocate such mortgaging of the future, while we also see industrial prophets in other lands raising strident voices advocating that these American methods, so called, be adopted and prosperity invoked. The speaker is not advocating such methods as sound economics, but simply states the facts as they exist.

Without doubt there are also many influences within modern industry that may best be described as "socializing." Our modern factory legislation and particularly our new compensation laws, indicate new views concerning the relation of industry itself as a means, in general, of supporting human life. How far we shall go in this direction remains to be seen.

Most important of all is the doubt that some phases of modern industry have set up in the minds of many as concerns democratic government. The fundamental principle in democratic government as organized in this country is that one man's opinion is as good as another's in all matters political. The great state of New York has just had a popular election at which nine constitutional amendments were submitted to the voters. Many of these amendments no doubt were but poorly understood by many people; perhaps the only one that was clearly understood, generally, was that which proposed an extension of the term of office of the Governor, and this was the only amendment to be defeated. Socrates long ago remarked that while every artisan resented criticism of his work by those not of his calling, every man believed that in matters political he could speak as an oracle. Surely times have not changed in this regard.

In a simple handicraft civilization where the methods of supporting life are simple and where the problems of life are common and easily understood, one man's opinion is probably as good as another's. Under such circumstances, for instance, trial by a "jury of one's peers" is without doubt logical and fair. But we are not living in such a simple state. Life, and particularly industrial life, has become exceedingly complex, and it has become increasingly difficult for men to "see life whole" as advocated by the old Greek philosophers. A large number of our problems, social, economic, and political, have a technical background and grow out of the basic industrial changes that have been noted in the foregoing. Their origin and the methods of their solution are far removed from the man in the street, and not infrequently from his elected representative. Hence we have the Muscle Shoals problem still with us after these many years, and we have the spectacle of Congress occupying a large part of its time debating a farm-relief bill which after passing both houses is vetoed by the President on the ground that it is *unsound economically*. And apparently his judgment meets with wide approval. No end of such examples can be cited, and any one who has served upon, say, the board of public works of any city, great or small, must have vivid recollections of the bungling efforts of duly elected city fathers to solve the simple technical problems incident to the administration of the city. How much more difficult is the problem of our congressmen and senators. The wonder is that they perform as well as they do.

Outstanding Problem of Democracy the Calling of Specially Trained Men to Its Service

Autocratic government orders things much more efficiently because it can call to its aid, if it will, the special skill and knowledge necessary for the solution of these problems. But it is better to be poorly self-governed than it is to be well governed in an arbitrary manner. The outstanding problem of democracy, therefore, is to call to its aid the groups of specially trained men who can assist in these matters. At the present time the tendency in government appears to be toward government by special interests or "blocs." Thus we hear much of the organized farmers, the merchants' bureaus, the lumber interests, the bankers, and so on. The influence of these groups, it is true, is indirect, but it is often effective. Thus at the present moment a congressional committee is holding hearings on tax reduction surrounded by groups of appellants, each clamoring for relief from taxation for the bloc it represents. The committee sitting like a jury will endeavor to evaluate the evidence and decide what to do! May Heaven help them and send them wisdom, for theirs is a difficult situation. Trying a man for murder is a much simpler jury affair.

Perhaps the most disheartening aspect of the situation is the widespread indifference of people at large to these changed conditions. The average citizen is pleased to enjoy the comforts of life that modern methods have brought to him, but apparently does not give much thought to the difficult social and economic changes that appear to be inseparably connected with the production of these comforts. Or if he belongs to the older school of thought he deplores the decadent age and mourns for the "good old days" that existed somewhere in the dim past, just where no one knows. When the danger to his social organization becomes too apparent he makes haste to "pass a law," often with little or no scientific inquiry as to reasons or results. An excellent case of this kind is now before us in the Mississippi flood. For many years hydraulic engineers have been advocating a national laboratory for the study of just such problems, of which they tell us we do not know enough to predict proper solutions. Now that the calamity has occurred there is the usual clamor for legislation, while competent engineers again try to point out the danger of waste and repetition of trouble if hasty legislation is passed, and stress the necessity of careful basic study of the phenomena of such occurences.

One of our greatest problems, therefore, is to bring to the aid of governmental bodies the technical advice and knowledge of our professional groups. This will be no easy matter, for obviously legislative bodies must be free to work out their own solutions. But, nevertheless, it would appear to be logical that if all of the professional groups had some means of expressing themselves nationally they could be of great service. The American Bar Association is such a body and one that has done much to advance sane legislation. The American Engineering Council is another similar agency that has already amply justified its existence. For it should be remembered that the professional groups all together constitute only a small part of our population. The entire body of technically trained scientists and engineers is but a small handful, relatively speaking. Yet this small handful has revolutionized industry and is now reforming our national habits and our economic and social needs. The methods by which all this has been accomplished are also applicable to the solution of some of these economic and social problems. It remains to be seen how these principles can be utilized to these ends. For if government of the people, by the people, and for the people shall fail us it will not be because of lack of able representatives or of loyalty of the people at large, but because we shall not be able to bring to bear upon these difficult national problems the same kind and degree of technical skill and knowledge that has brought them into being. May heaven send us wisdom.

Flying Should Be Safe[1]

THAT flying under properly organized conditions can be made as safe as any other form of modern transportation was the message sent by Harry F. Guggenheim, President, The Daniel Guggenheim Fund for the Promotion of Aeronautics, New York, to the 5000 delegates who attended the Sixteenth Annual Safety Congress of the National Safety Council. The paper by Mr. Guggenheim, who was unable to attend, was read by Lew R. Palmer, Past-President of the National Safety Council and a member of the A.S.M.E. Safety Committee. Mr. Guggenheim said in part:

> If we examine the hazards of flying we find they can all be traced to physical sources. Flying is nothing more than counteracting the law of gravity. Safety in flight, however, involves much more than the mechanics of the plane itself, but, unless we centered our attack on some one problem we could only touch the surface. For this reason we are trying to solve the problem of the plane itself. In April the Daniel Guggenheim Safe Aircraft Competition with prizes totaling $150,000 was announced and entries are now being received.
>
> The modern airplane is a light but excellent structure, and it is very rarely that we hear of a structural failure in the air. The air-cooled aviation engine is now a highly reliable mechanism. Careful installation of the power plant has eliminated fire hazard to a large extent. But while the airplane has made marvelous progress in economy and load-carrying ability since its early days, it is still lacking in safety from an aerodynamic point of view.
>
> However, even when we have found our "safe airplane," we still have other obstacles to overcome, such as the nature of the terrain, clouds, darkness, wind, fog, and sleet.
>
> Concerted efforts are now being made by scientists to devise some way of solving the fog problem. Perhaps it will be some way of dissipating the fog, of penetrating it with light rays, or of perfecting instruments to guide the pilot in flight and in landing military planes which must have speed and maneuverability rather than safety as primary requirements.
>
> When we solve this problem of safety, people will want planes, and by quantity production they will be in the reach of thousands of people.

[1] From an article in *Public Safety*, October, 1927.

General Applications of Photography to Mechanical Engineering

Its Use in Optical Stress Determination, Recording Invisible Radiation and Practically Instantaneous Occurrences, Study of Explosions, Ground and Aerial Surveying, Studying Rapidly Moving Objects by Means of Retarded Motion Pictures, Etc.

By C. E. K. Mees,[1] Rochester, N. Y.

PHOTOGRAPHY is used in science and industry primarily to make a record which can then be studied and measured. It is the possibility of making a permanent record of temporary phenomena which has caused photography to replace eye observation in so many of the sciences.

In astronomy eye observation has been replaced almost entirely by photography, and the modern astronomer rarely looks through his telescope at all. Directing a small finder upon the objects he wishes to observe, he photographs them, with exposures the duration of which depends upon the luminosity of the objects to be observed but which frequently run into many hours. The patient measurements of stellar positions made with the micrometer have now been superseded entirely by measurements of photographic plates upon which positions can be determined with far greater precision and convenience than could be attained with the micrometer eyepiece.

As with the telescope, so with the microscope; photography is displacing visual examination, and in the case of the microscope as used in engineering work, especially in connection with metallurgy, photographic observation is of the greatest importance.[2]

Photography as a Recording Medium

An application of photography to simple recording on a quite different plane is that of the so-called "Factograph" camera invented by W. F. Folmer.[3] This camera, shown in Fig. 1, includes a spool of sensitive paper on which the record can be made, a lens and lighting box being placed in front of it so that when the camera is pressed down on an object to be photographed, lamps supplied by dry batteries will illuminate it and the object will be in focus on the paper. Perhaps the most important application of the Factograph camera is to the reading of telephone meters. The reading of these meters is greatly expedited by their photography in the special camera devised for the purpose, and a permanent record is made from which the customers' bills can be made out, the chances of error being thus very greatly diminished.

Another special device carrying out the same idea is that due to G. L. McCarthy, who has designed a camera intended to photograph upon a strip of motion-picture film all the checks passing through a bank. This provides a permanent record which greatly diminishes the risk of fraud.

Another camera which is so specialized, however, that it has not been made commercially, is that designed by Gardner and Case of the Bureau of Standards for photographing the interior of a rifle barrel.[4] An apparatus for this purpose was built by Nakamura,[5] but in Nakamura's system there is a foreshortening and lack of uniformity of scale over different parts of the photograph. In the instrument designed by the Bureau of Standards the entire inner surface of the bore can be photographed step by step. The optical system employed is shown in Fig. 2. It consists of a periscope with a prism at the end through which a very small image, 4 mm. × 1 mm. in area, is formed on the film, the area to be photographed being lighted by the lamp shown at L. This periscope has to be inserted in the barrel of the rifle, which is made to travel continuously so that the whole surface of the barrel is represented by six strips of film.

Fig. 1 The Factograph Camera

Application of Photography to Stress Determination

An important application of photography in connection with engineering is to the registration of the appearances obtained in the optical determination of stress by the methods first de-

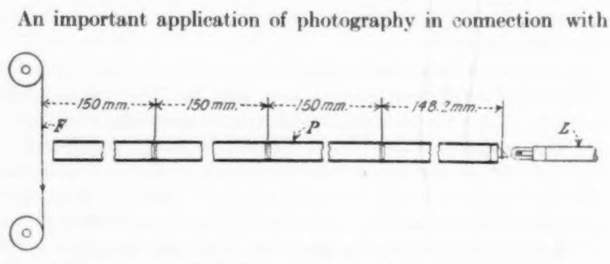

Fig. 2 Optical System Employed for Photographing Interior of Rifle Barrel

(Reproduced from *Journal of the Optical Society*, 1926, p. 159.)

[1] Director of Research, Eastman Kodak Company.

[2] This subject is dealt with at length in "Photomicrography and Its Application to Mechanical Engineering," by F. F. Lucas, page 205 of this issue.

[3] "Factograph Camera," *Am. Gas Light Jl.*, 1915, vol. 103, p. 141; *Machinery*, 1915, vol. 22, p. 75. See also "Finger Print Camera," published by The Folmer Graflex Corp., Rochester, N. Y., 1926.

Presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers, at a session held jointly with the Optical Society of America.

[4] "A Camera for Photographing the Interior of a Rifle Barrel," I. C. Gardner and F. A. Case, *Jl. Opt. Soc.*, 1926, p. 159.

[5] S. Nakamura, "Photographing a Rifle Barrel," *Brit. Jl. Phot.*, 1926, vol. 73, p. 19.

scribed by Prof. E. G. Coker.[6] This method is commonly known as photoelasticity, although the title would seem to be scarcely justified. An excellent description of its application to engineering problems is given by Heymans.[7] A model of the specimen in which the stresses are to be determined is made in some transparent substance such as glass or, more conveniently, celluloid, and this model is placed between two nicol prisms crossed on each other and fitted with a quarter-wave plate so as to supply a beam of circularly polarized light. Any stress will be shown by the appearance of colored fringes. This method in the hands of Heymans and A. L. Kimball, Jr.,[8] is giving much valuable information to engineers.

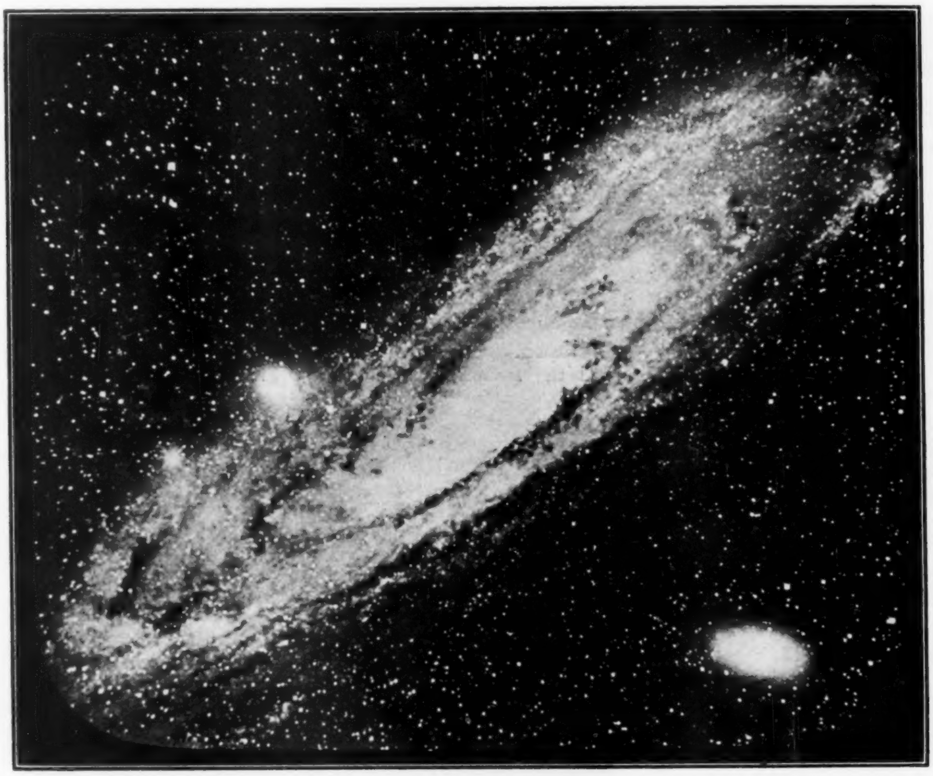

FIG. 3 SPIRAL NEBULA
(Reproduced by courtesy of Yerkes Observatory, Williams Bay, Wis.)

Photographing Spiral Nebulae

It is also possible to study by photography things which cannot be seen or at any rate cannot conveniently be measured with the eye. Thus, it may be that the light is too faint to see but that we can make use of the property of the photographic plate upon which on long exposure the energy is integrated and the image builds up, so that finally we obtain a photograph representing objects which cannot be seen at all. A well-known case of this is the photography of the great spiral nebulae. These vast objects covering great areas of space are very faint, but by giving long exposure it is quite possible to photograph them and show their extension. It is only by means of photography that we have been able to study the spiral nebulae and to realize that they represent universes, our whole universe, in which the sun is placed, being only a single spiral and perhaps one no greater in extent than the other spiral nebulae which can be photographed (Fig. 3).

Applications of Photography to Invisible Radiation

It was early found that when photographic material was exposed to the spectrum it would record radiation to which the eye was not sensitive. The first radiation so recorded was beyond the violet in the spectrum and was termed the "ultra-violet" radiation. By means of photography the ultra-violet spectrum down to the point where the radiation is absorbed by air becomes as accessible as the ordinary visual spectrum, and indeed, the great convenience of photography led physicists to rivet their attention upon the ultra-violet and violet ends of the spectrum and diverted attention from the red and green rays, which, while much more luminous to the eye, were not easily recorded upon the earlier photographic materials. This balance has now been redressed, and modern photographic materials are sensitive to the whole of the visible spectrum as well as to the ultra-violet, while recent sensitizing methods have enabled us to photograph even the longer infra-red to which the eye is insensitive, and thus again to push our investigations into a region inaccessible to the eye[9] (Fig. 4).

Not only can the whole range of light be photographed, but the extremely short waves generated from a cathode tube, and which are known as "X-rays" or "Roentgen" rays, also affect photographic materials. To a very large extent investigations by means of the X-rays, which are of such importance in medicine and are rapidly becoming important also in industry, depend upon photographic methods.[10]

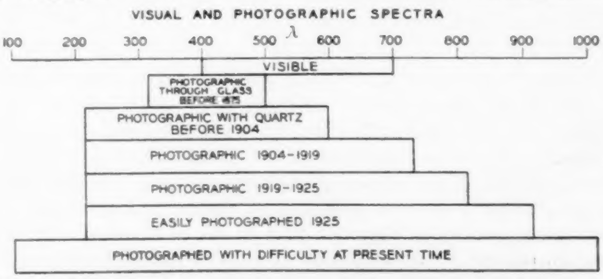

FIG. 4 DIAGRAM SHOWING PROGRESS IN RECORDING THE SPECTRUM

[6] "The Optical Determination of Stress," *Phil. Mag.*, 1910, vol. 20, p. 740. See also, "Professor Coker's Apparatus," a catalogue published by Adam Hilger, Ltd., London, 1924. This contains references to many papers on the subject.

[7] "Photo Elasticity and Its Application to Engineering Problems," *Tech. Eng. News*, 1922, vol. 3, p. 80.

[8] "Photo Elasticity and Its Relation to Gear Wheels," *Am. Mach.*, July 2, 1925, vol. 63, pp. 7 and 51. See also *Automotive Industries*, June 11, 1925, vol. 52, p. 1021.

[9] C. E. K. Mees, "The Color Sensitivity of Photographic Materials," *Jl. Frank. Inst.*, 1926, p. 525.

[10] This is dealt with at length in "X-Ray Examination of Structural Materials," by Wheeler P. Davey, p. 213 of this issue.

An application of photography by invisible radiation is that of Svedberg and Anderson,[11] who have used the fluorescence produced by ultra-violet light on ancient inks for the deciphering of palimpsests; that is, manuscripts in which the original writing has been erased or faded out and a new document has been written on the old paper. Such palimpsests are often important because when parchment was very valuable it was not uncommon for ancient manuscripts, frequently those of the classic authors, to be used by later writers to record their own comparatively worthless reflections. Svedberg showed that by illuminating such manuscripts by ultra-violet light and then photographing through a filter which did not transmit ultra-violet but which did transmit the fluorescent light generated by the action of the ancient ink on the ultra-violet light, the manuscript could be deciphered.

Another problem in the elucidation of destroyed documents was solved by Davis[12] of the Bureau of Standards, who found that the ink of a document which had been burned would often still affect a photographic plate when placed in contact with it for some time.

Photography has been used very widely for the study of forged or altered documents, and there is a considerable literature dealing with this subject. An interesting discussion of the application of photography to the detection of erasures and alterations will be found in "Photography as a Scientific Implement."[13]

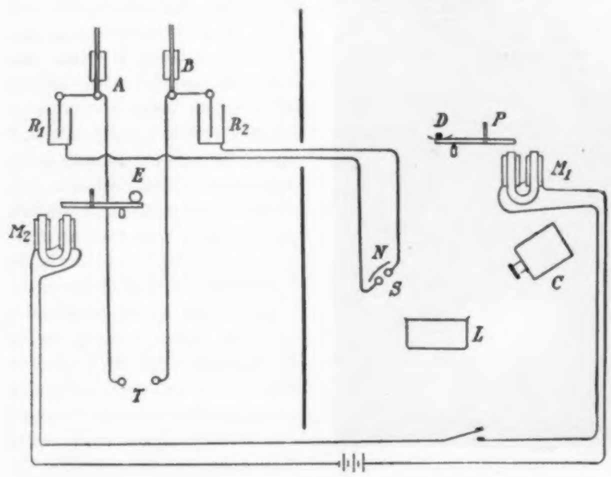

Fig. 5 Apparatus Used for Photographing Splashes
(Reproduced from "Photography as a Scientific Implement," p. 365.)

Photographing Occurrences Lasting too Short a Time to Be Seen

Another field for the use of photography, because direct observation is impossible, is that of occurrences which last for too short a time to be seen. It is well known that a dispute in which Leland Stanford was involved as to whether a galloping horse had four feet off the ground at one time led to the employment of Muybridge in order to determine the matter photographically, an experiment which played a part in the development of the motion picture.[14] With modern high-speed photographic materials and rapidly moving shutters, exposures of one one-thousandth of a second in an ordinary camera are perfectly possible, while by means of the electric spark very much shorter exposures can be used to record phenomena of which the separate phases cannot be observed at all. Thus, Worthington has made an interesting study of splashes produced by dropping a ball into water.[15] The apparatus used is shown in Fig. 5. The ball shown at D is allowed to drop upon the breaking of the current in the electromagnet M_1. At the moment when the splash occurs, the spark S illuminates it, and this spark is produced by the ball E falling past the terminal T, which discharges the condenser system through the spark gap. The time at which the discharge takes place can be varied by altering the distance through which E has to fall, and thus a photograph can be obtained at any period of the splash. The earliest photographs of rapidly moving projectiles were those made about 1881 by Professor Mach of the University of Prague.[16] Professor Mach used the so-called "schlieren" apparatus devised by Toepler for making visible those portions of a transparent medium which differ but slightly from their surroundings.[17] The general arrangement of the apparatus is shown in Fig. 6. A large achromatic lens of good quality and rather long focus is illuminated by means of a spark, and the image of the spark is about two-thirds covered by a diaphragm (a). The field is then seen uniformly illuminated by the light that passes under the diaphragm, since every part of the image of the spark receives light from the whole lens. Any object as shown at point b which produces a difference of refraction in the field will produce a difference in the illumination and thus become visible.

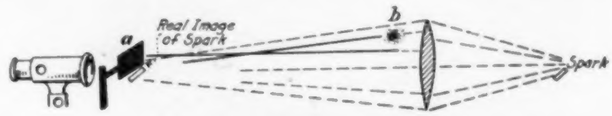

Fig. 6 Toepler's "Schlieren" Apparatus
(Reproduced from "Physical Optics," R. W. Wood.)

Fig. 7 Flame from Blasting Gelatine
(Reproduced by courtesy of Nobel's Explosives Co., Ltd., England.)

In 1893 C. V. Boys[18] introduced a method of photographing

[11] "Fluorescence Photography by Means of the New Wratten Ultra-violet Filter," *Phot. Jl.*, 1923, vol. 47, p. 30; also, *Phot. Korr.*, 1915, vol. 25, p. 205.

[12] "Action of Charred Paper on the Photographic Plate and a Method of Deciphering Charred Records," *Bureau of Standards Scientific Paper No. 454*, p. 445 (1923).

[13] Chap. XIV; D. Van Nostrand Co., New York, 1923.

[14] "The History of the Motion Picture," by T. Ramsaye. Simon & Schuster, New York, 1926, p. 21.

[15] "A Study of Splashes," Longmans, London.

[16] "An Account of Scientific Applications of Photography," *Jl. Camera Club* (London), 1893, vol. 7, p. 110. This article contains a summary of the author's earlier papers.

[17] *Wied. Ann.*, vol. cxxxi, p. 33. See also "Physical Optics," R. W. Wood, Macmillan & Co., New York, 1924, p. 94.

[18] "Electric Spark Photography or The Photography of Flying Bullets by the Light of Electric Sparks," *Nature*, 1893, vol. 47, pp. 415 and 440.

bullets in flight by their direct shadow, the sound waves and other air disturbances produced by the flight of the bullet being recorded on the photographic plate owing to the fact that their refractive indices differ from that of the surrounding air. This work of Boys was developed by Quayle,[19] who greatly improved the timing method. R. W. Wood[20] has used this same method for photographing sound waves.

Stanton has used a similar method for obtaining shadowgraphs showing the pressure of gases ejected from nozzles under different pressures.[21]

Photographic Study of Explosions

An important application of very high-speed instantaneous

Fig. 8 Flame from Permitted Explosive
(Reproduced by courtesy of Nobel's Explosives Co., Ltd., England.)

photography is in connection with the study of explosives. Thus, the flame for a given mass of explosive can be photographed and a record made from which can be judged the suitability of the explosive for use under conditions where such flames are dangerous, as, for instance, in coal mining. Fig. 7 shows the flame given by 100 grams of blasting gelatine when photographed upon a moving film. Fig. 8 shows the flame produced by 150 grams of what is known as a "permitted" explosive, in which the flame is reduced to such dimensions that it is no longer dangerous.

An article on the photographic methods used in studying the detonation of explosives which contains useful references to other papers on the subject is that written by Parrott and Gawthrop.[22]

Ellis and Robinson[23] instead of photographing such flames on a revolving film designed an apparatus containing a high-speed rotating shutter by which single photographs of flames could be made at any interval of time after their initiation, and this has been used by Ellis and Wheeler[24] for studying the movement of flame in closed vessels. This work is of course of importance in connection with the nature of gas explosions.

Photographic Registering Instruments

The use of photography for recording the movements of physical instruments is very old. In Tissandier's "Handbook of Photography,"[25] published in 1876, a chapter is devoted to photographic registering instruments in which a description is given of the application of photography to the registration of the barometer and thermometer. The principle involved can be illustrated by a recent instrument used in our laboratory to record the movement of liquid in a tube.[26] The tube is placed above a slit in the top of a box through which a band of sensitive paper is drawn by means of clockwork. The tube is connected in this apparatus to a sedimentation apparatus in which a precipitate is falling, this precipitate changing the level of the liquid in the tube, and the progress of the sedimentation is recorded on the sensitive paper.

Svedberg has used a similar method for recording the position of equilibrium attained by a suspension sedimenting in an ultracentrifuge,[27] with which he has obtained some remarkable results in the determination of the molecular weight of proteins.

In this instrument, as in those described by Tissandier, a direct record is made of the movement which occurs, but more often the phenomenon is recorded by means of the movement of a mirror which reflects a beam of light or of an object, such as the fiber of a string galvanometer, which will obstruct the light. Tissandier describes the use at Greenwich of recording magnetometers in which the ray reflected from the mirror of the magnetometer is thrown upon sensitized paper.[28] As the simplest example to illustrate this we may take the vibrations of a tuning-fork prong. If a ray AB is incident on a mirror B fixed on the side of a prong of a fork, as shown in Fig. 9, it will be reflected along BC, and as the fork vibrates the reflected ray will also vibrate through an angle twice that described by the mirror. If the reflected ray fell on a stationary plate P, it would make a horizontal straight line of short length, but if P is allowed to fall vertically during the process, a curve is traced out showing the vibratory motion of the prong. Instead of this falling plate, the light might be received on a disk of sensitized paper a or

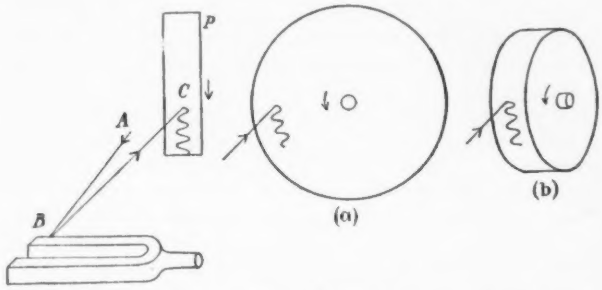

Fig. 9 Recording of Vibrations from Tuning-Fork Prong

[19] "Spark Photography and Its Application to Some Problems in Ballistics," *Bureau of Standards Scientific Paper No. 508*, 1925, p. 237.
[20] Loc. cit., Ref. 17.
[21] "Flow of Gases at High Speeds," T. E. Stanton, *Proc. Roy. Soc.* (London), vol. (A), 111, 1926, p. 306.
[22] "Photographic Measurement of Rate of Detonation of Explosives," G. St. J. Perrott and D. B. Gawthrop, *Jl. Frank. Inst.*, 1927, p. 103.
[23] "A New Method of Flame Analysis," Ellis and Robinson, *Jl. Chem. Soc.*, vol. 127, 760 (1925).
[24] "The Movement of Flame in Closed Vessels," Ellis and Wheeler, *Jl. Chem. Soc.*, vol. 127, p. 764 (1925).
[25] Low, Marston, Low. and Searle, London, 1876, p. 179.
[26] R. H. Lambert and E. P. Wightman, "An Automatic Recorder for Measuring Size-Frequency Distribution of Grains," *Jl. Opt. Soc. Am.*, 1925, vol. 11, p. 393.
[27] The Svedberg and Herman Rinde, "The Ultra-Centrifuge, a New Method for the Determination of Size and Distribution of Sizes of Particles in Amicroscopic Colloids," *Jl. Am. Chem. Soc.*, 1924, vol. 46, p. 2677. See also, The Svedberg and Rabin Fahraeus, "A New Method for the Determination of the Molecular Weight of the Proteins," *Jl. Am. Chem. Soc.*, 1926, vol. 48, p. 430.
[28] Loc. cit., Ref. 12, p. 276.

on a motion-picture film or strip of sensitized paper wrapped around a drum rotating at uniform speed shown at *b*. The optical system necessary to produce a sharply defined curve would consist of a powerful light source such as a condensed filament lamp or arc, the light of which passes first through a condensing lens and then through a small hole. The distance of the light from the lens is adjusted until the image of the light source is obtained covering the mirror. In front of the mirror is placed a lens which forms an image of the hole on the plate where the record is desired. Cameras are made to carry the falling plates or rotating drums carrying paper.

At the present time this system of optical recording is the widest application of photography in connection with engineering and applied science of all kinds. At the same time it should be pointed out that it is merely an incidental application of photography, a beam of light having the advantage over a stylus, which can record on paper by making a mark, in that it is a pointer without weight.

The applications in this field are numberless, and I can only select a few for illustration. Perhaps the first that will occur to the mind is the recording of the movement of the earth itself. In a seismograph a delicately poised pendulum boom is swung by any movement of the earth and traces on a sheet of bromide paper the record of an earthquake disturbance. Such records are often of great practical use. It is common for earthquakes to be reported from the seismographs with a definite indication of their position many days and sometimes weeks before precise information as to what has occurred can arrive from a stricken spot. Thus, definite news as to the great Kansu earthquake was not obtained until two weeks after the earthquake had occurred.

Turning from a vast earth tremor to a minimum earth tremor, Norton has used a similar method for recording the oscillation of a hard floor when it is walked on.[29] Midgley[30] has designed an optical gas-engine indicator by which the pressure which is occurring in the cylinder of an automobile engine can be recorded. Fig. 10 shows some curves obtained, the top one showing smooth combustion and the second the production of a knock, while the bottom curve shows preignition.

The principle of the "optical lever" for measuring the deflection of moving parts of instruments has been adopted by Dolby in his optical load-extension recorder.[31] This instrument gives load-extension diagrams with high precision for different materials. Beam and jockey-weight inertia effects, which often occur in the ordinary testing machine, are eliminated, and the time effect on tensile tests may be determined even at great speeds of testing. The Roberts-Austen recording pyrometer and the Paladin double-recording galvanometer are other examples of application of this same principle.

Pressure-recording devices using photographic film have been used at Langley Field and are described in the notes of the National Advisory Committee for Aeronautics.[32] A continuous curve may thus be plotted of the control surfaces of a plane during flight, and the information obtained is made available for the design of airplanes and the instructing of pilots. A recording manometer with thirty capsules on it has been designed in the laboratory to measure the air pressure exerted on different parts of the wings, and thirty records are made simultaneously in this instrument.

An instrument for recording the thickness of cotton fibers has been designed by the Cotton Research Company.[33] The cotton fiber passes over a lever carrying a mirror, so that variations of thickness are recorded on a rotating drum.

Another type of vibration which is usually recorded photographically is that of sound. Professor Low, working with Adam Hilger, Ltd.,[34] has designed a very simple audiometer in which the sound wave affects a diaphragm carrying a mirror, and a beam of light from it makes a record of the sound. This has been used for the analysis of speech and of music. A record of a sound wave made in a somewhat different manner by the use of a condenser microphone with an oscillograph has been obtained by Obata of Tokio[35] to determine the quality of building bricks. The specimen is struck in the middle with a small steel hammer, and in this way the pitch of resonance and the degree of damping can be observed.

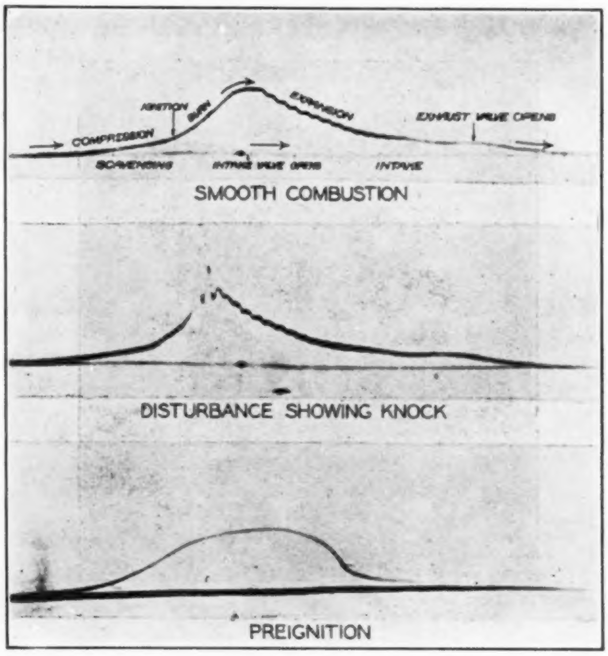

Fig. 10 Pressure in Engine Cylinder of an Automobile
(Reproduced by courtesy of Thomas J. Midgley, Jr., Dayton, Ohio.)

Utilization of Photography in the Reproduction of Sound and Its Applications

Recently photography has been utilized not only for the recording but for the reproduction of sound, and the application of this in connection with motion pictures may possibly be of great importance in the future. Since sound is a vibratory motion, it can of course be recorded as a series of bands upon a film moving uniformly. Thus, if a narrow slit be placed over the film and the sound is allowed to impinge upon a diaphragm controlling an oscillograph mirror, the excursions of the mirror will result in a sawtooth record of which the periodicity will conform exactly to that of the sound.[36] If this record is then

[29] "A New Instrument for Recording Linear Accelerations," F. H. Norton, *Jl. Frank. Inst.*, vol. 198 (1924), p. 231.
[30] *Jl. Soc. Automotive Eng.*, vol. 10 (1922), p. 359.
[31] Loc. cit., Ref. 12, p. 313.
[32] "Technical Notes of the National Advisory Committee for Aeronautics," nos. 64, 100, 112, 150, 154, and 156.
[33] "Cotton Thread," *Saturday Evening Post*, Feb. 26, 1927, p. 140.
[34] "Low-Hilger Audiometer," *Engineering*, Jan. 25, 1924, vol. 117, p. 108; see also, D. C. Miller, "The Science of Musical Sounds," Macmillan & Co., New York, 1926.
[35] "The Discrimination of the Quality of Brick by Means of Sound," *Jl. Frank. Inst.*, 1927, vol. 203, p. 647.
[36] A. C. Hardy, "The Requirements of Correct Tone Reproduction in the Recording of Sound Motion Pictures," *Trans. Soc. Mot. Pic. Eng.*, 1927, no. 31, p. 475.

passed between a light source and a photoelectric cell it will modulate the current in the cell, and when this current is transformed again through an amplifying and diaphragm system into sound, the sound will be reproduced. Instead of an oscillograph which produces the sawtooth record, a sensitive electric lamp can be used in which the intensity depends upon the current, which in turn is controlled by the microphone, and in this case the record will be a barred modulated record.[37] The combination of music with motion pictures is in this way quite possible, and the results have already found public favor.

The electrocardiograph is an instrument for the recording of the weak electric currents which accompany physiological phenomena, such as the beat of the heart.[38] For these short-period currents of small amount the string galvanometer is replaced by a single fiber, frequently of silvered quartz, stretched within the field of a powerful electromagnet. Very small currents cause the fiber to be deflected in the strong magnetic field, and its deflections can then be registered photographically. Owing to the low inertia of the system, the period of this galvanometer is extremely small.

Detecting Change in an Object by Means of Photographs Taken at Different Times

It is often important to detect a change in an object after a lapse of time. The application of photography to this purpose was mentioned by Tissandier in the early book to which reference has already been made,[39] and it is rather interesting that as early as 1876 Tissandier could see possibilities of photography which are even not yet completely realized.

> One of our friends, a military engineer, engaged in superintending some railway works [he wrote], was addressing some words of blame to the contractor who was employed in building a bridge. He complained of certain faults of construction, and especially at the slow progress of the work.
>
> "But I beg your pardon," replied the contractor. "Are you quite sure your information is correct, for you have not personally visited the works?"
>
> "I have not stirred from home, it is true," replied the engineer; "but here is a mirror which is sent to me regularly, and which tells me every week what quantity of stones you have collected, what number of bars of iron you have got together." He then took from his drawer some photographs.
>
> "I employ a photographer," he continued, "who sends me every morning a picture of your work taken on the spot. Here is the complete series. The moving crane, which a fortnight ago was three yards from the second pile and which advanced five yards the preceding week, has moved very slowly for the last eight days. It is necessary, I tell you, to be more active. All that you do there, I see here; the photographs which are sent to me give me even the appearance of your workmen, and if one of them has been idling while the picture was being taken, I can take him to task from my office here."
>
> I listened to this singular conversation, and I said to myself, that the future would work out more perfectly this system already made use of. The day may perhaps come when the negative will be taken at a distance by means of the electric wire; and if some reader exclaims, "Impossible!" I shall refer him to certain telegraphic systems lately discovered which allow us to anticipate this new miracle. (I believe that there is nothing Utopian in the notion that, ere long, means will be discovered of telegraphing a photograph from one end of the earth to the other; a most desirable consummation for the Metropolitan Police, and for the *Illustrated London News* and *Graphic*.)

The detection of changes in photographs can be accomplished in various ways. If the two photographs are viewed in a stereoscope, any changes which have occurred will usually be manifest at a glance, the displacement of an object causing it to appear at a different position in front or behind the body of the photograph.

Another method which is especially made use of in astronomy is that known as the "blink microscope," in which two photographs are viewed through an instrument by means of which first one photograph and then the other can be seen, the change being accomplished rapidly. In this case, any object which occurs in one and not in the other appears to move when the change is made and it can thus be detected.

Still another method is that detailed in a paper by Stillman of the Bureau of Standards.[40] Stillman makes a positive from one photograph of such a density that it just neutralizes the negative of the other photograph. When the two are superimposed, any change which has occurred between the two photographs is at once manifest.

A method for determining the true vertical in buildings, chimneys, columns, etc. has been described by Mallock.[41] It is obvious that a true vertical line is formed if any point in a structure is joined with the reflection of that point in the free surface of a liquid. A structure therefore may be photographed from two viewpoints (at right angles or nearly so), there being just in front of the lens an artificial horizon in which the reflection of the structure appears and is photographed simultaneously. The photograph so obtained gives a lasting record of the visible details of the structure as they existed at the time of making the exposure.

Photographic Surveying

Colonel Laussedat of the French Army[42] was the pioneer in the application of photography to surveying, and since photographic surveying is more suitable for mountainous countries, it is in the Alpine regions of Europe and the mountain chains of Canada that the largest areas have been surveyed photographically. Dr. Deville, late surveyor general of the Dominion of Canada, studied the subject very exhaustively and wrote a number of books on the subject, and the Russian surveyors have also used photographic methods on a large scale, especially in their surveys of Siberia.

In order to make a photographic survey, two photographs are taken of the same area from different known positions which are plotted on the map. Lines are then drawn from the positions to each identifiable point on the map and object in the photograph until the complete survey is accomplished, this plotting being done after the manner of a plane-table survey but with the advantage that the detailed plotting is done in the office and is therefore independent of the weather, the only work done in the field being the photography. The cameras used for the purposes are of rigid construction and have leveling mounts so that they can be leveled precisely. Elaborate phototheodolites have been devised for the purpose, notably a beautiful instrument designed by Zeiss,[43] but simpler cameras are also quite satisfactory provided that they are rigidly made. No considerable area can, of course, be mapped without a skeleton of positions determined relatively to each other with precision, and a primary triangulation is therefore made over the area to be mapped,

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[37] E. I. Sponable, "Some Technical Aspects of the Movietone," *Trans. Soc. Mot. Pic. Eng.*, 1927, no. 31, p. 458.

[38] Einthoven, *Arch. ges. Physiol.*, 1895, vol. 60, p. 101; also *Proc. Roy. Soc. Med.* (Clinical), 1912, vol. 5, p. 183; also Lewis, "The Mechanism and Graphic Registration of the Heart Beat," Paul Hoeber & Son, New York, 2nd Edition.

[39] Loc. cit., Ref. 24.

[40] "A Photographic Method of Detecting Changes in a Complicated Group of Objects," *Bureau of Standards Scientific Paper No. 392*, 1920, p. 437.

[41] "A Photographic Method of Determining the True Vertical in Buildings, etc.," *Jl. Camera Club* (London), 1896, vol. 10, p. 129.

[42] A. L. Higgins, "Photography," Cambridge University Press, London, or Macmillan & Co., New York, 1926. This book contains a bibliography on the subject. See also, "Photography as a Scientific Implement," p. 349.

[43] N. V. Maatschappy voor Landopmeting, "Terrestrial and Aerial Stereophotographic Surveying," The Hague, 1922.

other points then being interpolated from the photographs.

Another method of photosurveying is by the use of the principle of stereoscopy. Two phototheodolites are put at the opposite ends of a measured base and exposures made in which the same objects are included. From the photographs distances can be measured by the use of the stereocomparator designed by Professor Pulfrich of Carl Zeiss.[44] A notable advance in this field of stereoscopic photosurveying was made when Captain von Orel of the Austrian Army developed the stereoautograph, which is a three-dimensional pantograph which can be used in conjunction with a stereocomparator and will plot a map directly from the photographs. Stereophototopography is now the most advanced of photographic methods of survey; its accuracy is high and it is very rapid. Its drawbacks are the high cost of the instruments, the necessity for base measurement, which is not always easy, and the considerable weight to be transported.

In connection with the whole subject of photosurveying it should be mentioned that recent improvements in color sensitizing have made it possible to take photographs at very great distances by the use of the extreme red light, which penetrates haze to a much greater extent than light from the visible parts of the spectrum.[45]

Aerial Photography

Another photographic method of surveying which has come into great prominence recently is that of photography from the air. The use of photography from the air during the war was of the very greatest importance, the camera being an aid to the fighting arms on both sides. At the present time aerial photography is used both for the preparation of pictures, such as those of estates for sale, which give a general idea of the topography, and also for surveying where the precision, while slightly inferior to a ground triangulation, is yet often sufficient for practical purposes. Aerial photography is used very much in surveys of difficult country, such as that including forests and lakes, and for the surveys of cities. A fire survey, for instance, can be made very rapidly and cheaply from the air. By means of efficient cameras now available continuous records can be made by aerial photography, and these can then be pieced together to make a map. It has been found recently that aerial photographs show features which are invisible to a person on the ground, and in this way traces of destroyed structures and work can be found persisting which are often of great interest in archaeology. Thus, it is still possible to trace in parts of England the lines of the Celtic fields and ditches which were entirely destroyed when the Saxons invaded the country and established their own system of agriculture. The old filled-in ditches affect the growth of the crops so that from the air they can still be seen.[46]

Photomechanical Typesetting

An application of photography having an immediate commercial aspect is that of photomechanical typesetting. Hislop has described the different machines devised to replace the printer's "mold and matrix," the most promising of which is, perhaps, the Hunter-August machine.[47] This instrument will rapidly print on a strip of sensitized film any size letter from 6-point up to 96-point type. The developed and specially processed film is attached directly to the cylinder of the printing machine and printed off much as letterpress is now printed.

[44] Loc. cit., Ref. 39.

[45] Ibid., Ref. 8.

[46] "Air Survey and Archaeology," O. G. S. Crawford, Ord. Survey Prof. Papers, New Series No. 7, H. M. Stationary Office, London, 1924, p. 18.

[47] "Photo-mechanical Typesetting," Pamphlet printed by Students of the London School of Printing, 61 Stamford St., London, 1923.

Motion-Picture Photography with Time Acceleration or Retardation

This paper has dealt with the wide applications of still photography to such an extent that the field of motion-picture photography has been somewhat crowded out, but there is no question that motion-picture photography will in the future be used very largely in connection with engineering. There is one feature of motion-picture photography which makes it valuable in many fields of scientific study. The motion picture enables us to rehearse events and to modify the rate at which they occur. We can run the film backward, reversing the time stream, or we can project much more rapidly than the rate at which the pictures were taken, thus accelerating time; or we can take pictures rapidly and project them slowly, thus slowing down rapidly moving objects, so that we can observe their movement.

An extreme case of the slowing down of movement is that obtained with the high-speed camera built by Heape and Grylls for the British Admiralty, with which, photographing 10,000 pictures a second, they were able to show the action during the penetration of shells into hardened-steel targets.[48] Another wonderful camera is that invented by Baron Shiba of Japan. Such high-speed cameras would be of great use in many fields of engineering. It is possible by means of ordinary high-speed cameras, with which action can be retarded 4 to 8 times, to show the way in which a turning leaves a bar on a lathe or in which a milling tool or twist drill works. The late Frank Gilbreth used high-speed motion pictures in his analyses of the motions of workers as he did also stereoscopic photographs, and such studies are probably only in their infancy.

Future Applications of Motion Pictures to Engineering Problems

Frequently the taking of pictures very slowly or with a time lapse makes it possible to accelerate an action so that its movement can be studied and realized as a whole. There are many movements which occur the nature of which is not realized because of the long time that they take, so that the mind cannot follow the action as a whole. Growing plants, for instance, twist and move in the most extraordinary manner. If photographs are taken slowly of a growing plant and then projected rapidly, the whole plant is seen to writhe as if it were an animal rooted in one place. Slow changes occurring in engineering operations can be integrated in the same way, and theoretically it is possible to photograph the progress of construction of a bridge or a building step by step, and eventually to run off the film showing the whole growth of the erection. Simple apparatus is now in preparation by which the cost of working can be reduced very greatly owing to the adoption of amateur standard in place of standard motion-picture film. There is no doubt that in the future there will be many applications of motion pictures to engineering problems.[49] A general paper on scientific applications of photography has been published by G. E. Matthews and J. I. Crabtree.[50] This contains many references to applications in the engineering field.

[48] W. H. Connell, "The Heape and Grylls Machine for High Speed Photography," *Jl. Sci. Inst.*, Dec., 1926, vol. iv., p. 82. See also P. J. Risdon, "Filming Rapidly Moving Objects by Means of the Heape and Grylls Rapid Cinema Machine," *Sci. Am.*, 1924, vol. 130, p. 166; C. Francis Jenkins, "Motion Picture Camera Taking 3200 Pictures per Second," *Trans. Soc. Mot. Pic. Eng.*, 1923, no. 17, p. 77; C. Francis Jenkins, "The Jenkins Chronoteine Camera for High Speed Motion Studies," *Trans. Soc. Mot. Pic. Eng.*, 1926, vol. 25, p. 25.

[49] C. Tuttle, "Motion Photomicrography with the Cine-Kodak," *Trans. Soc. Mot. Pic. Eng.*, 1927, no. 30, p. 213.

[50] "Photography as a Recording Medium for Scientific Work," *Jl. Chem. Educ.*, 1927, vol. 4, pp. 9 and 200.

Photomicrography and Its Application to Mechanical Engineering

Description of Equipment of Bell Telephone Laboratories for Technical Microscopy, Together with Particulars Regarding the Application of High-Power Metallography to the Study of Structures Found in Hardened Steel

By FRANCIS F. LUCAS,[1] NEW YORK, N. Y.

Fig. 1 Operating Room, Laboratory for Technical Microscopy, Bell Telephone Laboratories, Inc., New York

PERHAPS more than any other, the mechanical engineer is interested in the quality of the metals which he uses. Metallography is that branch of science which deals in the anatomy of metals and teaches how the structure changes under the influence of mechanical and thermal treatments. It is the means by which good, poor, or indifferent physical properties are explained on the basis of structure. With control of structure comes control of physical properties.

Some ten years ago a survey showed that the microscope was regarded generally as an instrument which had yielded its basic store of knowledge. However, the actual record of accomplishment appeared to be hardly a tenth part of the potential resolving ability of the best optical systems. This led to the development of high-power metallography.

Gradual improvements in technique led to better and better resolution. With resolution approaching the theoretical limits of available optics, further steps into the structure of matter were taken with the ultra-violet microscope and the new objectives of very high resolving ability.

An increase in magnification with a falling off in definition has been termed "empty" magnification, and the apparent inability of workers to secure crisp, brilliant images at high magnifications has led to the general acceptance of a theory that magnification in excess of about 1500X is of little value.

Not only is it possible to secure crisp, brilliant images at high powers, but it is also possible to secure the potential resolving ability of the best optical systems. The applications of these remarkable optical systems to the solution of industrial and scientific problems in the field of metallography will be illustrated.

For example, what happens when hardened steel is tempered may be watched quite clearly, and thus we learn a little more about the phenomena of the hardening of metals. Particles of matter so small that their dimensions are reckoned in millionths of an inch or in terms of a few hundred atom diameters can be resolved clearly. These particles can be caused to grow or to disappear almost at will by suitable thermal or mechanical treatments.

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[1] Bell Telephone Laboratories, Inc., New York.

Presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers, at a session held jointly with the Optical Society of America.

Lead cable-sheath alloys, which in service now and then develop traits of intercrystalline brittleness and fail, have responded to high-power metallography so that we have secured a knowledge of the causes underlying such failures. It appears that the phenomena of aging in lead-antimony cable sheath is not far different from what appears to be the mechanism of tempering in hardened steels.

What the ultimate limit of vision may be, suffice it to say that no one knows. We are working now on the theoretical limit of vision with present optics and visible light. The possibilities of ultra-violet light are in the infancy of exploration, but the indications are that we shall learn much about the structure of matter through the aid of the ultra-violet microscope. Ultra-violet light has selective characteristics as to absorption and reflection by matter, and these characteristics often differ from the reactions secured with visible light on the same structures.

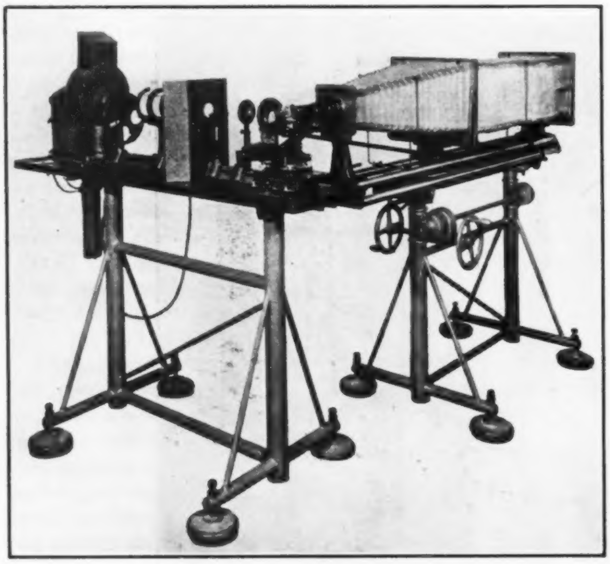

FIG. 2 EQUIPMENT FOR HIGH-POWER METALLOGRAPHY USING VISIBLE SPECTRUM

The possibilities with visible light are by no means exhausted. Greater resolving power is secured by increasing numerical aperture. In our laboratories we have revived the mono-brom-naphthalene objective. Two of these objectives are now in the experimental stages of investigation. They have a numerical aperture (N.A.) of 1.60 and we have been able to demonstrate remarkable resolving ability over the objectives of 1.40 N.A.

Resolution and magnification are not synonymous terms. Resolution denotes the ability of a lens system to define or resolve very fine structural detail in the object as separate and distinct units in the optical image. Resolution usually is expressed in terms of lines per inch, but this has its disadvantages as well as its advantages. Structural detail in the object does not occur usually in the form of a ruling or grating—more often as very small globular or roughly crystalline particles in a matrix from which they have formed. There are good reasons for believing that these precipitated particles range in size from atomic proportions upward. The early evidences of the presence of such particles in a metal, the appearance of carbides in martensitic needles, for example, is revealed clearly by present microscopic technique when the particles are approximately 300 atom diameters. That is, we can see these particles as individual units, but before they have reached the dimension given we have knowledge that they are present. In this latter case, groups of particles are resolved differently from the way in which the matrix is from which they have formed; the individuals are not distinctly resolved, but colonies of the units manifest themselves.

In order to see these very small particles, magnification is necessary, so it will be readily understood that while magnification and resolution are separate terms and define different things, nevertheless they do go hand in hand.

It became apparent in the very early stages of this development that if one wished to utilize the utmost in resolving ability it would be necessary to secure crisp, brilliant images at high magnifications.

We are told that a lens system has certain inherent limitations beyond which one cannot go. It is held that no lens system can reproduce a point in the object as a point in the image. The point becomes a halo, and common experience has taught that when the magnification is pushed beyond 1000 or 1500 times, the halo or spurious disk becomes of such proportions as to ruin definition.[2,3] By the means employed in high-power metallography, which have been described elsewhere and therefore will not be repeated here, it is now possible to photograph specimens at 6000X with substantially the same quality of definition as formerly was recognized as representing a good image at about 1000 diameters magnification. That is to say, by reducing the diameter of the halo or spurious disk it has been possible to utilize higher magnifications and thus deal successfully with very small particles of matter.

FIG. 3 ULTRA-VIOLET MICROSCOPE

The equipment used for high-power metallography with visual light is the Zeiss Martens metallurgical equipment. This equipment has been modified in several minor ways. For ex-

[2] "High-Power Photomicrography of Metallurgical Specimens," Trans. Am. Soc. for Steel Treating, vol. iv, 1923.

[3] "High-Power Metallography—Some Recent Developments in Photomicrography and Metallurgical Research," *Journal Franklin Institute*, vol. 201, 1926.

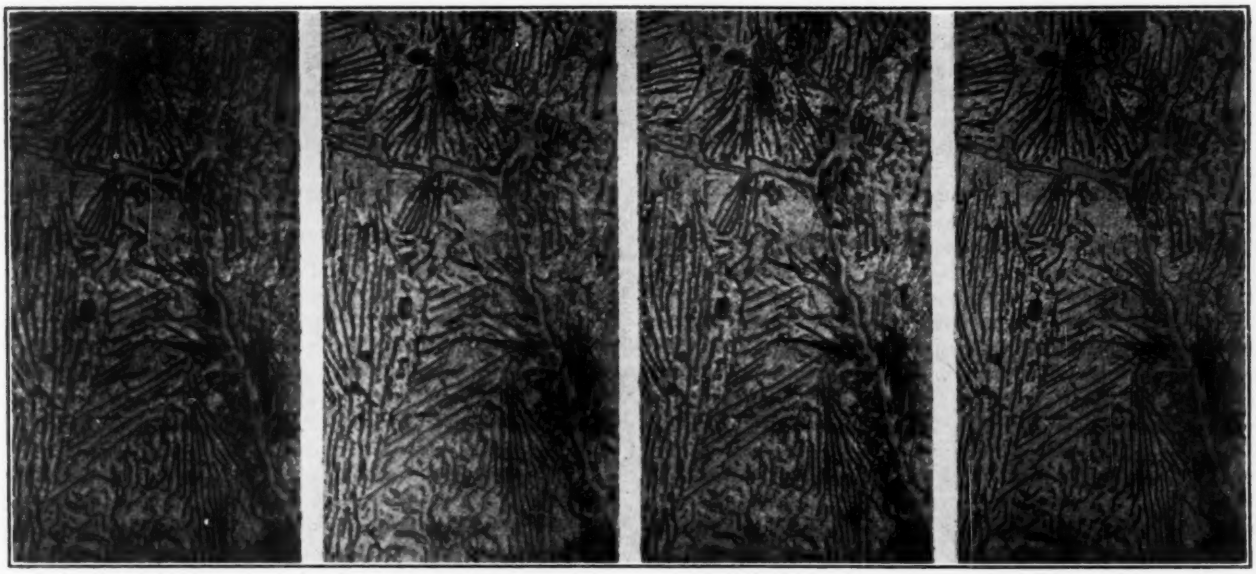

FIG. 4 ILLUSTRATING RESULTS WITH MECHANICAL FOCUSING OF ULTRA-VIOLET EQUIPMENT
(Focus changed successively by $^{1}/_{16}$ micron. Magnification 1800X.)

ample, the stands are supported on cast-iron base plates which in turn rest on sponge-rubber pads. This method of suspension is employed to minimize the effects of vibration transmitted to the equipment from the floor. The Martens equipment is illustrated in Fig. 2.

For high-power work it is desirable to use light of as short a wave length as possible because, it will be remembered, resolution improves as the numerical aperture of the objective increases or as the wave length of light used decreases. In order to take advantage of the situation suitable filters are used to exclude the red and the green rays and to pass only the blue rays. In actual practice the filters do not absorb all of the red and the green rays but permit some to pass. The dominant wave lengths lie in the blue range of the visible spectrum.

The ultra-violet microscope is illustrated in Fig. 3 and was discussed in an introductory paper before the American Institute of Mining and Metallurgical Engineers;[4] later the equipment was demonstrated before the New York Electrical Society, the occasion being in honor of the fiftieth anniversary of the birth of the telephone.

The ultra-violet equipment was designed by Kahler and Von Rohr, of the Zeiss works, in 1902. Theoretically the ultra-violet microscope should have opened many new channels of investigation because it has a potential resolving ability nearly twice as great as that of the best apochromatic objective of

[4] "An Introduction to Ultra-Violet Metallography," Trans. A.I.M.E., vol. lxxiii, 1926.

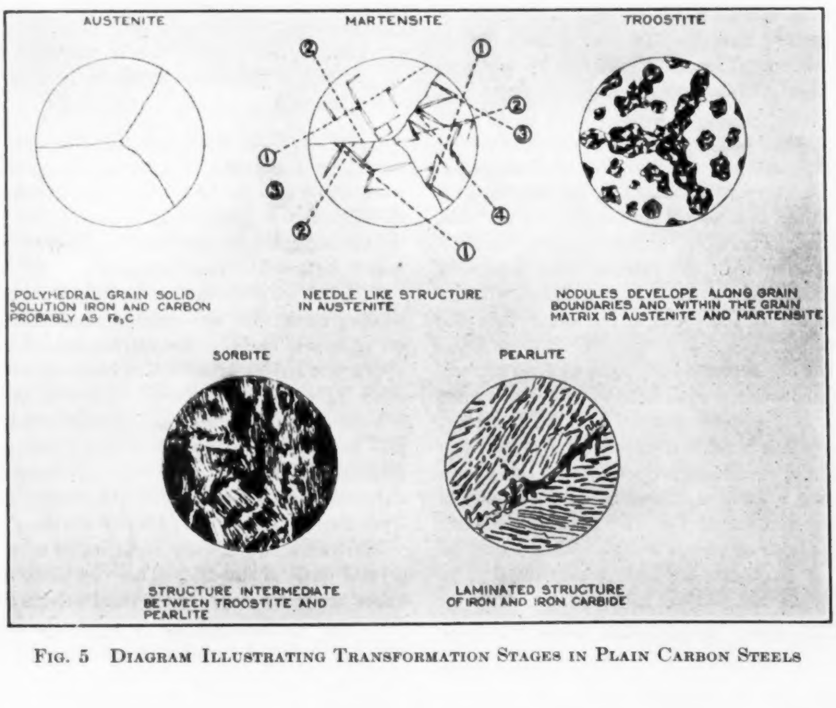

FIG. 5 DIAGRAM ILLUSTRATING TRANSFORMATION STAGES IN PLAIN CARBON STEELS

1.40 N.A.; actually the equipment appears to have very little to its credit in the way of original discoveries.

Whether the potential resolving ability of an optical system can be achieved in practice depends on many factors other than the ability to purchase an expensive equipment.

There seems to be every reason to believe that we can go much farther with the microscope than we have gone up to the present time. The limitations do not appear to be optical ones but of a more commonplace kind such as learning how best to prepare specimens for microscopic examination. Structures are now being clearly resolved as aggregates in our laboratory with visual light which less than four years ago appeared practically structureless under the same conditions. The feeling at the time was that fine detail did exist—that the structure was an aggregate—and the ultra-violet equipment and also the high-aperture objective (N.A. 1.60 mono-brom-naphthalene immersion objective using visual light) were thought to be the only means by which these structures could be resolved. However, improvements in technique and in the preparation of specimens have since enabled us to resolve these structures very clearly with the identical optical system which four years ago failed to accomplish the same end. These details of structure of the constituents martensite and troostite of hardened steel were presented for the first time at the International Congress for Testing Materials held at Amsterdam, Holland, during September, 1927, and will appear in the forthcoming proceedings of the Congress.

The ultra-violet equipment employs monochromatic light because ordinary optical glasses are opaque to ultra-violet light and therefore a wide variety of materials are eliminated for use in correcting the lenses. Certain glasses are now available which do transmit ultra-violet light,[5] and through the courtesy of Dr. W. C. Taylor of the Corning Glass Company we have obtained and transmitted to the Zeiss Works a number of specimens of glass of optical quality. The characteristics of these glasses are now being studied by Dr. Kahler and his staff, and there now appears to be some probability of having a corrected objective for a band in the ultra-violet. When the monochromats were first developed these glasses were not available and thus it was necessary to use quartz as the lens material.

The light source in the ultra-violet equipment is a spark-generating equipment using cadmium electrodes. The light is decomposed spectroscopically and the 2750 line isolated for use in illuminating the specimen. The total light available is very weak, hence the desirability of having an objective corrected for a wider band.

The image may be focused on a fluorescent screen in a device called the "searcher eyepiece," but the intensity of illumination is not sufficient to insure an exact focus. One cannot tell with certainty whether the image is in focus, just coming in to focus, or just going out of focus. Therefore, to rely on the searcher-eyepiece method of focusing with the present weak source of light means that it is almost entirely a matter of chance whether an exact focus is secured. If the focus is not exact then the results are of little value.

The present objectives are corrected for light of 2750 Au, and they do not perform satisfactorily with light of any other wave length. This has been amply demonstrated in our laboratory.

The element of chance has been eliminated by a mechanical means of focusing. The slow-motion adjustment of the microscope has a drum bearing a graduated scale. Each division of the scale denotes a change in focus of 2 μ. By a suitable pointer and scale the motion has been amplified so that each 2 μ may be divided into 32 parts. A photographic plate measuring $3^1/_4 \times 8^1/_2$ in. was procured to fit the sliding plate holder, and by means of a suitable mask four consecutive rectangular exposures may be made on each plate. The focus is changed slightly for each exposure.

The image is approximately focused by means of the searcher-eyepiece method and final focus then secured by the mechanical method. With the high-power objective the focus is so exact that the changes in focus are made by increments of $^1/_{16}$ μ. The results secured by this method are illustrated in Fig. 4.

Some Observations on the Hardening of Steel

Fig. 5 illustrates in a general way the transformation stages in steel. Austenite is the condition of stable equilibrium of a plain carbon steel at high temperatures. By slowly cooling to room temperature the structure becomes pearlitic and the steel is soft. If the steel is cooled rapidly it becomes very hard and transition structures as illustrated occur. The exact nature of these structures has been of foremost interest to metallographers and others interested in metal.

About five years ago high-power metallography was applied to the study of the structures found in hardened steel. An attempt was made to produce large, well-formed needles of martensite in grains of austenite. This would enable us to deal with individual needles and not with an indistinct felted mass such as one finds in most commercial steels, which harden by quenching. If individuals could be dealt with it should be possible to learn something of their habits and formation.[6] The following tentative conclusions were drawn from the preliminary report:

1 That a martensitic needle is a decomposition along the octahedral crystallographic planes of austenite.
2 That a martensitic needle is confined to an area of uniformly oriented austenite; i.e., a needle never crosses a grain boundary or a twinning plane.
3 That martensitic needles respond to sodium picrate, an etch which selects iron carbide. (They also etch with nitric or picric acid reagents which do not stain or attack iron carbide.)
4 That martensitic needles have a mottled, granular appearance, and sometimes also a line structure depending probably on orientation.
5 That a martensitic needle is an aggregate and not a solid solution.
6 That a martensitic needle marks a decomposition of the austenite probably to alpha iron and iron carbide highly dispersed.

Since the early work many improvements in the technique of preparing specimens have been worked out and the ultra-violet microscope and the mono-brom-naphthalene objective have been developed to a point of usefulness. The study has been carried on almost continuously during the past five years and a great many observations have been made.

While these observations are not complete, they do seem to be leading to certain well-defined conclusions which can be based on observed facts. The mechanism of the hardening of steel appears to have a great deal in common with the manner in which other alloys are hardened. Likewise when steel is tempered it seems to undergo the same general structural changes as transpire in certain non-ferrous alloys which have a faculty for becoming relatively softer as they age from the hard state. Lead-antimony cable-sheath alloy consisting of 99 per cent lead and 1 per cent antimony is an alloy of the class mentioned.

Martensite is generally regarded as a brown needle or acicular crystal with a mid-rib. This describes its general appearance under the microscope, but several writers have referred to "white

[5] Hood, "A New Ultra-Violet Transmitting Glass," *Science*, Sept. 17, 1926.

[6] "The Micro-Structure of Austenite and Martensite," Trans. Am. Soc. for Steel Treating, December, 1924.

Fig. 6 Martensitic Needles in a Hardened Specimen of an Iron-Carbon Alloy
(Illustrating what may happen when the specimen is tempered by the work in preparing it for microscopic examination. Magnification 3500X.)

martensite:" that is, the needle structure instead of being brown is white. The reason for this difference is quite apparent from work done in our laboratory.

The results of the study are too comprehensive to be included in detail in a general paper of this kind, but some brief account may be of interest.

Since one object of the study was to determine what takes place when hardened steel is tempered, it was necessary to know that the hardened structures are not altered by the preparation work. A satisfactory means for preparing hardened steel specimens has been worked out, and we believe that very little if any tempering actually takes place. This was not true at the time of the early work alluded to above. The contrast is quite apparent as will be seen from Figs. 6 and 7. Fig. 6 was deliberately tempered in the preparation work, whereas Fig. 7 shows the same specimen when prepared so as to avoid tempering.

If a good-quality plain-carbon steel of about 1 per cent carbon is heated to 1000 deg. cent., and quenched in an ice and brine solution, the structure of the steel becomes martensitic. That is, it consists of a felted mass of needle-like forms, and usually some troostite will be found along the old austenitic grain boundaries and here and there throughout the grains. Usually the appearance of troostite is localized to some zone where the rate of cooling probably was retarded. The troostite occurs in the form of nodules.

When such a specimen is prepared for microscopic examination so as to avoid tempering and is etched lightly with a nitric acid solution a white field results, dotted with dark particles. The field appears white due to the acicular white needles, or "white martensite" as it has been called. It is the filling between the needles or the matrix which dissolves away in etching and not the needles themselves. Hence the structure appears to be a felted mass of white needles separated from each other by dark particles. Actually these dark areas denote places which are more responsive to the etching reagent. So instead of developing brown needles in a white field, actually one develops white

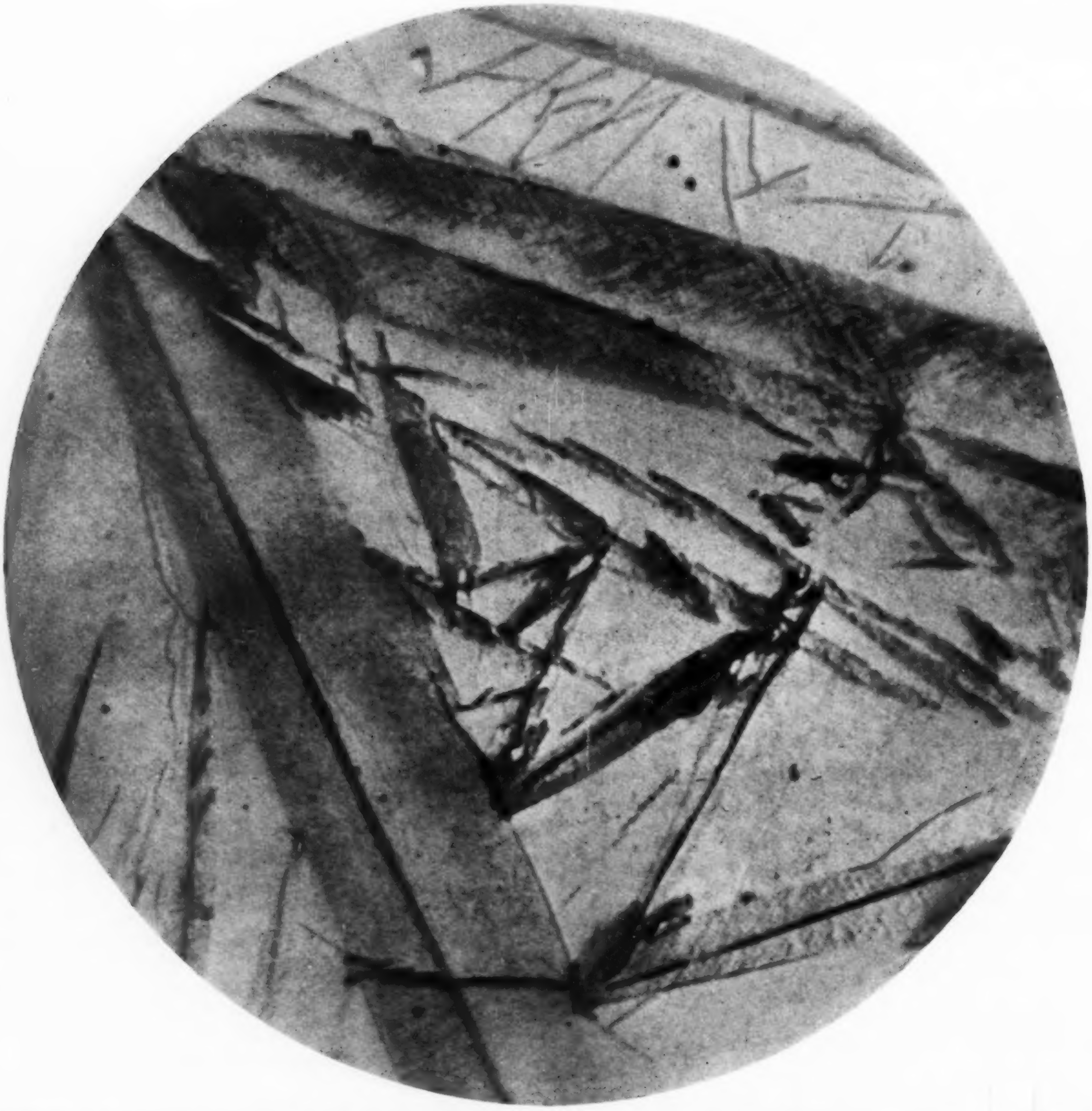

Fig. 7 The Identical Specimen Shown in Fig. 6, but Now So Prepared as to Avoid Tempering. Magnification 3500X

needles in outline because he dissolves away the more soluble material between the needles. As the specimen is etched more and more the white forms persist, but the interspaces dissolve away and appear black. If long-continued etching is employed the white areas or white martensitic needles develop cubic etching pits. The white needles have the characteristics of solid solutions but probably they are not, the distinction depending only on what we have thus far been able to resolve with the microscope. We at least know that particles in metals may be resolved when their dimensions are of the order of about 300 atom diameters, so that if white martensite represents maximum hardness, which it probably does, then the precipitated particles of carbide (or troostite) must be less than 300 atoms in diameter and very likely much less. Professor Sauveur regards martensite as troosite in an austenitic matrix, and there is much in the evidence which seems to confirm this conclusion.[7]

[7] Sauveur, "The Current Theories of the Hardening of Steel—Thirty Years Later," Trans. A.I.M.E., vol. lxxiii, 1926.

Troostite, however, is now known to be alpha iron and iron carbide. Improvements in resolution during the past year or two have made it possible for us to break up this structure. What formerly was regarded under the high-power microscope as a solid solution now proves to be an aggregate by the same method of analysis.

When the white martensitic structure is first developed the white forms show many very fine polishing scratches. The scratches are not visible to the eye as one views the image through the microscope or on the focusing screen, but are made known by photography. The photographs often show that a scratch will appear in one white needle, disappear as it passes the dark interspace (because here the metal has been dissolved away), and reappear in the next needle.

The presence of the scratches may be regarded as indicating one of two things: either the white needle-like areas are soft and scratch very readily or else they are very resistant to etching, and consequently the very fine scratches are not obliterated by

FIG. 8 "WHITE MARTENSITE" IN 1.1–1.5 PER CENT CARBON STEEL NOT TEMPERED IN PREPARATION

(Note that it is the fillings and not the needles which etch; the needles are quite resistant to etching and show very fine polishing scratches. Magnification 1750X. Reduced from original 3500X.)

FIG. 10 "WHITE MARTENSITE" IN 0.90 PER CENT CARBON STEEL WITH ONE NEEDLE PARTIALLY TEMPERED. MAGNIFICATION 1750X

(Reduced from original 3500X.)

an etching attack before the interspace structure is developed.

It seems very improbable that the white needles can be soft, because a specimen of the kind described will measure in hardness about 600 Brinell. If the needles were soft they would impart a measure of ductility to the specimen, but in reality the specimen is hard and brittle. So we may eliminate from consideration the possibility of the white needles being soft and thus scratching more readily than the interspaces.

However, we do find that the white needles are very resistant to etching, and here lies the answer as to why the very fine scratches remain in evidence when the specimen is rather lightly etched.

Here and there throughout a specimen of this kind will be found needles which etch more readily than the white ones. Such needles may shade from light brown to almost black. Usually they are free of scratches and are mottled or granular in appearance under the high-powers. The dark needles appear to be white needles which have tempered slightly during cooling of the specimen. Occasionally needles are found with a dark brown or tempered interior and a white exterior, showing quite conclusively that the appearance of color in the needle on etching is indicative of a change in structure of the white or untempered needle forms.

When a specimen of the kind described is etched very lightly

FIG. 9 "WHITE MARTENSITE" IN 1.1–1.5 PER CENT CARBON STEEL STARTING TO TEMPER. MAGNIFICATION 1750X

(Reduced from original 3500X.)

FIG. 11 "WHITE MARTENSITE" IN 0.90 PER CENT CARBON STEEL TEMPERED 10 MIN. AT 500 DEG. CENT. MAGNIFICATION 1750X

(Reduced from original 3500X.)

FIG. 12 "WHITE MARTENSITE" IN 0.90 PER CENT CARBON STEEL TEMPERED 10 MIN. AT 650 DEG. CENT. MAGNIFICATION 1750X (Reduced from original 3500X.)

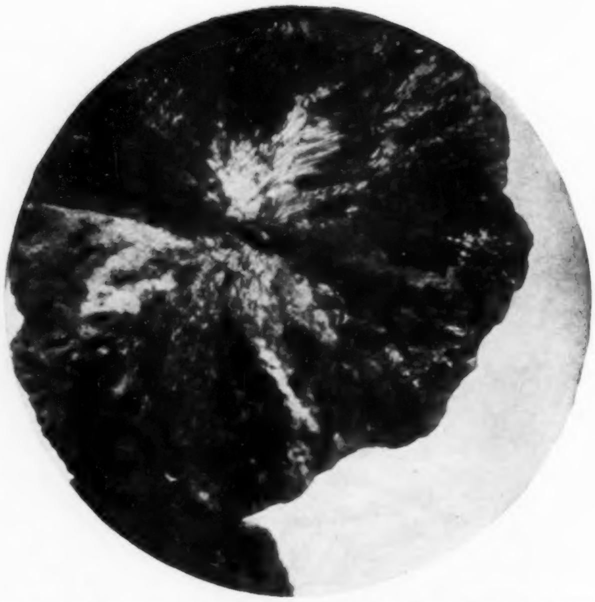

FIG. 13 A NODULE OF TROOSTITE IN 0.90 PER CENT CARBON STEEL. CONSTITUENTS SHOW INCIPIENT STRATIFICATION THROUGHOUT. MAGNIFICATION 1750X (Reduced from original 3500X.)

the brown needle forms will develop first because they are the least resistant to etching. Then the interspaces between the white needles will start to develop, and finally the white needles themselves will develop structure. If nodular troostite is present the troostite develops on etching in advance of the brown needles, although occasionally very dark granular needles develop which etch about the same as troostite.

The white needle forms might be called "residuals," because it seems obvious that irrespective of what the exact nature of the transformation is in martensite, the white areas represent zones in which the change has lagged behind the rest of the specimen. That is, they are more nearly austenitic than the interspaces, or the dark-colored needles. The changes are relative with reference to austenite, and the white needles indicate the first order of transformation.

When hardened specimens of the kind described are tempered at 100 deg. cent. the white residual areas, or white martensite, commence to darken and to take on a mottled appearance. In a specimen drawn at 200 deg. the change is more pronounced and at 300 deg. the needles are obviously an aggregate. At 400 deg. the specimen is fully mottled black and white, and structurally is a very fine aggregate with little contrast. At 500 deg. tiny carbide globules are formed and the specimen again develops contrasts as the background starts to clear somewhat. When tempered at 600 deg. cent. the old needle forms and the nodules of troostite, originally present in the quenched condition, are marked in outline by globular carbides. Small globular carbides appear throughout the whole structure. At 650 deg. the structure is fine spheroidized cementite in ferrite, but the old outlines of the needles and troostitic nodules still persist.

As these changes take place a change in hardness of course also takes place. The following is indicative of what happens:

Condition of specimen	Rockwell hardness, "C" scale	Condition of specimen	Rockwell hardness, "C" scale
As quenched...........	67	Drawn at 400 deg. cent.	49
Drawn at 100 deg. cent.	65	Drawn at 500 deg. cent.	41
Drawn at 200 deg. cent.	65	Drawn at 600 deg. cent.	32
Drawn at 300 deg. cent.	54	Drawn at 650 deg. cent.	28

When tempering is avoided in the preparation work, or at least very nearly so, the mechanism of decomposition may be pictured as follows:

At elevated temperatures the austenitic condition prevails and structurally the metal is composed of polyhedral grains of a solid solution of iron carbide in gamma iron.

When the specimen is quenched two things seem to happen:

1 Some or all of the iron changes from the gamma to the alpha state, as is well known.

2 Carbide is precipitated in very small particles. In the white martensite it is probably uniformly distributed and the particle size is less than 300 atom diameters—probably much less. In the tempered areas the carbide particles have grown in size probably by coalesence. At 100 deg. cent. their presence is detected and at about 400 deg. we can see them as definite particles.

Alpha iron and the carbide also appear as the constituent troostite which develops as nodules, usually about an inclusion or a void such as a minute gas pocket, or along grain boundaries. The nodules develop roughly globular in shape under ideal conditions and are found to be composed of radial grains. These grains at first were believed to be solid solutions, but recently the structures have been resolved:[8] As ability to resolve detail improves, it becomes apparent that the solid-solution state is a very transitory condition in troostite if it exists at all, and that in all probability these solid-solution grains are composed of alpha iron and iron carbide. In most nodules we now find grains just starting to break up, others which are fully statified pearlite, and others which are intermediate.

When a specimen containing nodules of troostite is tempered, the nodules do not grow in dimensions. They lose contrast as the carbide particles coalesce, and finally develop contrast again much in the same way as the martensitic needles behave. The final state is small fan-shaped grains of pearlite, but the old nodule outlines may be traced in a fully tempered specimen.

A number of photographs are reproduced to illustrate the points so briefly developed in this paper. A more complete discussion must await a later date.

X-Ray Examination of Structural Materials

Its Value in the Solution of Factory Problems, and in the Search for New Scientific Principles Which May Explain Known Facts or Be Applied to the Development of New Materials

By WHEELER P. DAVEY,[1] STATE COLLEGE, PA.

X-RAYS are useful in two ways to the mechanical engineer: first, in getting the factory out of manufacturing difficulties, and second, in the search for new scientific principles which may serve to correlate and explain known facts or which may be applied to the development of new structural products.

Solution of Factory Difficulties

Probably the first work which used X-rays in an effort to solve factory problems was done in the Research Laboratory of the General Electric Company, at Schenectady. While a large steel casting several feet in diameter and about a half an inch thick was being machined to size in the factory, a tiny crack was found in the metal. The casting was taken to the Laboratory and X-ray pictures were taken. These pictures showed a large hole in the inside of the metal. The spot indicated by the pictures was punched out and the hole was thus exposed to view. The use of X-rays in work of this sort was very expensive, so that soon other methods of testing were developed for smooth-faced metal which were just as good and considerably cheaper. The X-ray inspection of castings was therefore discontinued by the General Electric Company, but it has since been taken up by the United States Government at the Watertown Arsenal where an investigation was made of foundry processes. Occasionally, too, the Arsenal has made X-ray pictures of special castings where considerations of human safety have justified the high cost of such work. The most outstanding example of this was the X-ray inspection of some steam fittings for a new high-pressure steam line of the Boston Edison Company.

X-Ray Diffraction

It is in the discovery of new facts on which to base future factory processes that we find the greatest usefulness of X-rays. Practically all work of this sort depends upon the measurement of interatomic distances. These distances are so small that they cannot be measured directly. They are of the order of a hundred-millionth of a centimeter. By using X-rays of known frequency it is possible to use an X-ray diffraction apparatus as a micrometer for measuring these extremely small distances. The technique has been refined so that such measurements may be made easily with an accuracy of one part in a thousand. This sort of apparatus which was developed at the Research Laboratory of the General Electric Company, is now in use in the School of Chemistry and Physics at the Pennsylvania State College in investigating the properties of metals and their alloys. By measuring these minute distances it is already possible to predict some of the mechanical properties of metals, and to tell what happens when they form alloys. It is possible to show why copper is more ductile than iron, and why iron is more ductile than arsenic. Similar measurements made on tungsten, the material of which lamp filaments are made, make it seem that the Coolidge process now in use is the only process by which it can be made into a ductile wire.

A more detailed discussion of some of these points may be of interest.

Ductility

Plasticity, as applied to single crystals, has to do with the slipping of planes of atoms upon adjacent planes. It is related to ductility, for in order to be ductile a substance must be plastic in addition to having sufficient strength to keep it from breaking from the strain of pulling it through a die. The following discussion is strictly limited to single crystals, thus avoiding any complications incident to grain size. The changes necessary in following simple theory to make it apply to polycrystal materials will be obvious.

The results of experiment may be generalized by the statement that the plastic, ductile, and malleable metals such as copper, silver, gold, aluminum, etc. have face-centered cubic structures, and that the metals which are relatively less ductile, such as chromium and tungsten, have body-centered cubic structures. This rule is not, however, of universal application, for alpha iron is reasonably ductile and has a body-centered cubic structure. The reason for this exception is not known—it may be caused by some peculiar configuration of the valence electrons of iron. Single crystals of metals such as zinc, which are ductile in the cold only in certain directions through the crystal, have a "hexagonal close-packed" structure.

The work of Mark, Polanyi, and Schmid[2] and others makes it appear that, other experimental conditions being strictly the same, mechanical working of the metal causes slip along those planes in the crystal which have the maximum atomic population. It is a characteristic of the geometry of crystal structure that the planes of maximum atomic population are those which are farthest apart from each other. This means not only that the atoms in an individual plane are packed so closely together that they can hold to each other quite strongly, so that these individual planes of atoms are quite strong, but also that because of the distance from any one of these planes to its nearest similar plane, the interlocking of atoms from plane to plane is relatively weak, so that each plane can glide over its neighbor.

In the face-centered cube, the 1 1 1 (octahedral) planes[3] are those of greatest atomic population. There are four families of

[1] Professor of Physical Chemistry, School of Chemistry and Physics, The Pennsylvania State College.

Presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers, at a session held jointly with the Optical Society of America.

[2] *Zeit. f. Physik*, vol. 12 (1922), p. 58.

[3] There are several ways in which the atomic planes in crystals might be named. One of the most obvious of these is to name the plane by its intercepts on the axes of reference. The mathematics of crystal structure requires, however, the constant use of the reciprocals of these intercepts. For this reason it has become customary to name the atomic planes in terms of the smallest integers which are proportional to the reciprocals of the intercepts of the planes on the axes of references. Thus, the family of parallel planes whose intercepts are 1 ∞ ∞, 2 ∞ ∞, 3 ∞ ∞, etc. are all called 1 0 0 planes; in a cubic crystal they are the atomic planes parallel to the cube face. Similarly the family of parallel planes whose intercepts are $^1/_2$ $^2/_3$ 1, 1 $1^1/_3$ 2, $1^1/_2$ 2 3, etc. are called 4 3 2 planes. These integers are ordinarily called "Miller indices." Their use has practically displaced all other methods of naming the various possible planes of atoms in crystals.

1 1 1 planes symmetrically places about 70.5 deg. from each other. Each atom is symmetrically placed with respect to six other atoms in adjacent 1 1 1 planes, for there are three atoms which form an equilateral triangle in the plane immediately above, and three others which form an equilateral triangle in the plane immediately below. This means that each atom is directly below the center of a triangle of atoms of the 1 1 1 plane next above it and is directly above the center of a triangle of atoms of the 1 1 1 plane next below it. This close packing prevents loss of cohesion during slip. The 1 0 0 planes have nearly as large an atomic population, and are therefore almost as far apart from each other as the 1 1 1 planes. There are three families of 1 0 0 (cube face) planes mutually 90 deg. to each other.[3] Each atom in the 1 0 0 plane is equally spaced from four atoms in the adjacent plane below. The face-centered cube is therefore well supplied with both primary and secondary slip planes, and since both of these families of planes have high orders of symmetry, a face-centered cube can hardly escape being plastic in almost any orientation.

If the axial ratio of hexagonal close-packed crystal is greater than 1.735 the 0 0 · 1 planes are the planes of greatest atomic population and should therefore be the planes of primary slip. This is the case with zinc, whose axial ratio is 1.86. Each atom in an 0 0 · 1 plane is equally spaced from three atoms in the two adjacent planes much as in the case of the face-centered cube. But the 0 0 · 1 planes are the basal planes of the hexagonal prisms. There is, therefore, only one direction through a zinc crystal which is the optimum direction for mechanical working. The planes of next highest atomic population in zinc are the 1 0 · 0 planes. These are the faces of the hexagonal prisms. There are three families of 1 0 · 0 planes, all parallel to the z-axis and all 120 deg. from each other. The atomic arrangement is not as favorable to slip without loss of cohesion as in the case of the 0 0 · 1 planes, for a given atom is equally spaced between four atoms in the adjacent plane on one side of it, and between only two atoms in the adjacent plane on the other side of it. There will therefore be greater loss in cohesion during slip along the 1 0 · 0 planes of zinc. We should expect that, contrary to the common opinion, slip along the 1 0 · 0 planes of zinc will show different characteristics from slip along the 0 0 · 1 planes. Instead of nearly every plane sliding over its neighbors we should expect the 1 0 · 0 planes to slip in blocks. If a single crystal of zinc is stretched beyond its elastic limit we should expect the etch figures to show block slip along the 1 0 · 0 planes to a very much greater extent than along the 0 0 · 1 planes. O. E. Romig has reported that he has found this to be actually the case.

If the axial ratio of a hexagonal close-packed crystal is less than 1.735 (as is the case with magnesium), the atomic population of the 1 0 · 0 planes will be higher than that of the 0 0 · 1 planes. Primary slip will therefore occur along the 1 0 · 0 planes. Since there are three families of 1 0 · 0 planes, polycrystalline magnesium should be a little more plastic and ductile then zinc. Because of the unfavorable arrangement of atoms in the 1 0 . 0 planes of the hexagonal close-packed lattice, and since it has only three families of planes for primary slip and one for secondary slip, magnesium should be much less plastic and ductile than face-centered cubic metals like copper or aluminum, which have a favorable arrangement of atoms, and four families of planes for primary slip, and three for secondary slip. These conclusions are in accord with the results of practical experience.

In this connection cobalt is of peculiar interest. Pure cobalt is of only moderate ductility, while cobalt containing traces of impurities is fairly ductile. Hull[4] showed that pure cobalt may contain some face-centered cubic crystals, but that it usually crystallizes in a hexagonal close-packed lattice. Traces of impurities always make cobalt take the face-centered cubic structure, thus giving a rational explanation of the ductility of impure cobalt.

A consideration of the body-centered cubic lattice (Fig. 1) shows it to be an inherently less ductile structure than the face-centered cubic metals. The planes of highest atomic population, and therefore those which are farthest apart, are the 1 1 0 planes. The atomic arrangement is such that each atom in a 1 1 0 plane is equally spaced from two atoms in the adjacent plane above it and from two other atoms in the adjacent plane below it. This means that slip along the 1 1 0 planes is necessarily accompanied by very great loss in cohesion. The crystal will tend to crack during mechanical working. The planes of next highest atomic population are the 1 0 0 planes. The atomic arrangement is here more favorable to slip, for each atom is equally spaced between four atoms on each side of it, but it is of little use to have planes of secondary slip with good cohesion if cracking occurs along the planes of primary slip. The outstanding exception to all this is iron. Iron is body-centered cubic, and yet it is reasonably ductile. But this is not the only way in which iron is an exceptional metal. Its magnetic properties are such as to give rise to the term "ferromagnetic." It is the only known metal which, when sufficiently heated, changes from a body-centered to a face-centered cubic lattice. It is quite likely that the exceptional behavior of iron during mechanical working is tied up in some way with the underlying causes of its other exceptional properties.

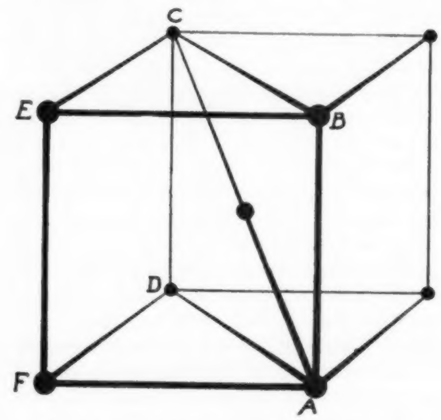

FIG. 1 A UNIT CUBE OF A BODY-CENTERED CUBIC LATTICE

Substances which crystallize with a simple cubic structure have practically no plasticity. An example of this sort of structure is ordinary NaCl. The rhombohedron of calcite has the same sort of structure except that the "cube" is deformed in the direction of its body diagonal. In the simple cubic crystal the 1 0 0 plane (cube face) is the plane of highest atomic population, and is therefore the plane of primary slip. In these planes each atom can only hold to one atom in the plane above it and one in the plane below it. The 1 1 0 plane (the dodecahedral plane) is the plane of second highest atomic population. Here, too, each atom can only hold to one atom above and one below. The simple cubic structure therefore tends to crack apart upon the application of very small forces—it is the least plastic of all the structures we have considered. It is said that the only way a sodium chloride crystal can be deformed at room temperature is to bend it while it is immersed in fresh water. Then if the bending is done so slowly that the rate of propagation of the cracks is less than the rate of solution in the water, the crystals may be successfully bent.

[4] *Phys. Rev.*, 17 (2), 571 (1921).

It would seem from the above that the ductility of materials is intimately connected with the marshaling of their atoms in space, and that, in general, the relative ductilities of two materials of comparable grain size and purity may be predicted from a consideration of their crystal structure.

Effect of Alloying

Studies of alloys are of increasing importance, especially when the study has to do with alloys of high purity. The results of experiments seem to show that intermetallic compounds are ionic in structure, i.e., the more electropositive metal seems to give over some or all of its valence electrons to the more electronegative metal. This results in a crystal structure of the nonductile type, thus explaining the universal rule that intermetallic compounds are brittle. There is every reason to believe, from X-ray data, that even so-called "solid solution" of one metal in another metal of different valence or of different atomic architecture is really ionic in nature. Each "atom" (really ion) of the "stranger metal" is to be thought of as attempting to form an intermetallic compound with the adjacent "atoms" of the "host." Such a picture is not only consistent with our X-ray diffraction data, but it explains many of the outstanding properties of alloys. For instance, if the valence electrons of the metals are tied up in attempting to make chemical combination between the metals, they are not so free to move. The alloy should therefore have a lower heat and electrical conductivity then the constituent metals. The electrostatic forces between the metallic ions should tend to warp the atomic planes in the crystals. This is again consistent with the X-ray evidence. It would be more difficult for warped planes to slide over each other, so that the strength of an alloy of the solid-solution type should (other things being equal) be greater than the strength of its individual constituents. Thus brass is stronger than copper or zinc, and alloy steels are stronger than pure iron. Since hardness, as ordinarily measured, involves a resistance to interplanar slip it is to be expected that in general alloys will be harder than their principal component.

The transfer of valence electrons from one metal to another in an alloy makes it important to continue our studies, using alloys of extreme purity. It has been found possible to make wires of certain pure binary alloys by never allowing the metal to become melted even when making the alloy. These studies are being carried on at the Pennsylvania State College in cooperation with the Research Laboratory of the General Electric Company. A discussion of the results so far obtained would be premature at this time.

Heat Treatment of Steel

Below 900 deg. cent. (1650 deg. fahr.) pure iron exists as "alpha iron." In each crystal in the metal the atoms are arranged in a definite configuration which is called a "body-centered cubic lattice." In order to visualize this, let us imagine a three-dimensional latticework built up of geometrical lines in such a way that they outline a group of cubes, all of equal size and all in close contact with their neighbors. Now let us imagine an atom of iron at each of the intersections of these lines. Each of these will therefore lie at the meeting point of eight of the imaginary cubes. Imagine, besides, an additional iron atom placed at the center of each of these cubes. This whole configuration is then a "body-centered cubic lattice." Each of the cubes in the imaginary framework of lines is called a "unit cube." It is customary among crystallographers to picture only one of these unit cubes, leaving it to the imagination of the reader to extend the lattice work for an indefinite distance in all directions. In alpha iron the side of the unit cube is 0.000,000,028,550 cm. (0.000-000,011,230 in.). Such a structure is called "body-centered cubic." Between 900 and 1400 deg. cent. (1650 to 2550 deg. fahr.), pure iron exists as "gamma iron." Each unit cube then has an iron atom at each corner and one at the center of each face. This structure is called "face-centered cubic." The steels have similar structures, but the transition temperatures are different. There is no X-ray evidence of so-called beta iron. Above 1400 deg. cent. (2550 deg. fahr.) iron exists as delta iron, which has a body-centered cubic structure like alpha iron.

Just as a regularly planted potato patch appears to have rows in different directions, depending upon the direction from which it is viewed, in the same way a crystal has planes of atoms in different directions through the crystal. The distance between adjacent planes will depend upon the direction of those planes in the crystal. As has already been explained, in a body-centered cube the planes which have the greatest spacing are those which contain a cube edge and a face diagonal. This plane is technically known as a dodecahedral plane, or as a 1 1 0 plane. When alpha iron is mechanically worked these 1 1 0 planes tend to slide over each other. In the language of the metallographers, those planes are "slip planes." These slip planes are held together by the attractive forces between the atoms in each plane and the atoms immediately adjacent in the planes on each side.

In gamma iron the planes which have the greatest spacing are those which contain two face diagonals. Such planes are called octohedral or 1 1 1 planes. In a face-centered cubic crystal, each atom in a given 1 1 1 plane is held principally by three atoms in the adjacent 1 1 1 plane on one side and by three other atoms in the adjacent 1 1 1 plane on the other side. This means that the slip planes in gamma iron are much more firmly tied together in the direction perpendicular to slip than are the slip planes in alpha iron, and the metal can be much more drastically worked. This is one of the reasons why steel is rolled above red heat.

Strength of Steel Over Pure Iron Due Largely to Bonding Action

It has been suggested by P. Ludwik that, in some cases at least, the effect of alloying elements is to introduce into the crystal structure atoms which are so large as to mechanically interfere with slip in much the same way that a rough spot on a shaft serves to interfere with the motion of the shaft in its bearing. In the case of carbon in steel there is still another possibility. Westgren has shown that in gamma iron most of the carbon lies between the 1 1 1 planes, but that in alpha iron most of it lies in the 1 0 0 planes which are parallel to the cube faces such as *ABEF* in Fig. 1. The crystal structure of alpha iron is such that there are natural tunnels running through each crystal parallel to each of the faces of the cube. These tunnels each have a cross-section as large as that of an iron atom. Half the total volume of a crystal of alpha iron is taken up by these tunnels. It is in these tunnels that most of the carbon in quenched steel is to be found. Although it has never been proved experimentally, there are good theoretical reasons for believing that the carbon "atoms" lie very near to the points where these tunnels intersect each other. There is also good reason for believing that at room temperature these carbon atoms are rather tightly fastened to some of the adjacent iron atoms. In this way the 1 1 0 planes in steel are bonded together more tightly than in pure iron, thus largely accounting for the greater strength of martensitic steel over pure iron. A somewhat similar bonding action may be used to account for the strength of austenitic steel. When it is remembered that in 0.17 per cent carbon steel the carbon atoms are on the average only five atomic diameters apart, it is easy to see why a small percentage of carbon by weight can exert such a profound influence on the properties of steel.

It is well known that carbon can migrate readily through alpha iron. If it were not for such migration it would not be possible to change martensitic steel into sorbitic steel by heating it.[5] It is believed that most of this migration takes place through the tunnels in the alpha structure. We may assume that if we had a perfectly homogeneous distribution of carbon in alpha iron, each carbon atom would be attached to adjacent iron atoms to form a "molecule" of Fe_3C. Such a picture is consistent with the known facts in the case of other compounds of carbon. If now this imaginary specimen of alpha iron is heated, each carbon atom will tend to move in one direction or another through the tunnels, breaking its union with one iron atom to form a new union with the next iron atom along its path. If two carbon atoms happen to move toward each other so that they find themselves in the same relative positions to each other and to the surrounding iron atoms that they would have in cementite (Fe_3C), the chance of their breaking away and migrating further will be greatly lessened. If a third carbon atom joins this pair, the chance of their migrating apart will be still less. The tendency in a carbon steel heated below the critical range, to allow carbon to migrate, is therefore always to form aggregates of Fe_3C. In gamma iron the carbon seems to be in solution in the iron. The face-centered cubic structure of gamma iron does not have the tunnels which characterize alpha iron, and each carbon atom seems to lie at the center of a tetrahedron of iron atoms. If a specimen of gamma iron containing carbon is lowered to the transition temperature for alpha iron and is then cooled slowly, there is plenty of chance for the migration of atomic carbon as described above, and the alpha iron contains pearlite, which may be regarded as Fe_3C, or at least as an intimate mixture of Fe and Fe_3C. If instead the specimen is cooled very rapidly, as by quenching, there is little chance for migration and martensite is formed in the alpha iron. If this is tempered, more opportunity is given for the migration of atomic carbon. This results in a larger aggregation of Fe_3C in alpha iron. If only a short time or low temperature is allowed for tempering, the migration is only sufficient to produce aggregates of Fe_3C of colloidal size, thus giving troostite. At longer times or higher temperatures the aggregates of Fe_3C are larger, thus giving sorbite. Still longer heating produces the massive (spheroidal) condition of Fe_3C known as cementite.

In gamma iron the possible spaces in which atomic carbon may exist have a configuration which is closely related to the configuration of carbon atoms in a crystal of graphite. If two atoms of carbon in gamma iron migrate so as to occupy the same relative positions to each other they would have in a crystal of graphite, their tendency to further migration will be decreased. This tendency will be further lessened by the chance arrival of a third atom of carbon in the position which it would have in graphite. The chance that such configuration will occur is increased as the number of carbon atoms in the iron is increased. For this reason it is easy to obtain "platelets" of graphite by long annealing of high-carbon steel.

Summary

Because of the dependence of mechanical engineering on the properties of structural materials, the X-ray has become a tool of considerable usefulness to mechanical engineers, not only in explaining facts which were previously known, but also in clarifying our ideas of structural materials, thus paving the way for the development of still additional materials to meet new requirements.

[5] This is the usual condition of hardened tool steel. Austenitic steel can be obtained by very drastic quenching of high-carbon and alloy steel from a high temperature. It is considerably "softer" than martensitic steel.

Measuring One-Billionth of an Inch

EQUIPMENT to measure changes in length of the order of a billionth of an inch recently has been devised by P. P. Cioffi of Bell Telephone Laboratories, New York. Such a length is so incredibly small that if it were possible to get paper that thin, over a million sheets piled on top of each other would be required to equal a piece of ordinary tissue paper in thickness. This length is just about a tenth of the diameter of an atom.

The need for so refined an instrument arose from studies of magnetic materials, which play such an important part in the telephone industry.

Until recently it had been thought and taught that pure iron was the most magnetic material it was possible to obtain. When G. W. Elmen of the Bell Telephone Laboratories discovered permalloy, all previous theory was therefore overthrown. This is an alloy containing 79 per cent of nickel, 21 per cent of iron, which has magnetic qualities far superior to pure iron alone. An immediate effort was made to build up a new theory to account for the remarkable properties of permalloy.

When a metal is magnetized, a loss occurs which evidences itself as heat. In addition, a small change in the dimensions of the metal is detectable. The change is almost inconsiderable, not over one part in 100,000, but is in opposite directions in iron and nickel; the former expands while the latter contracts in a magnetic field.

The myriad tiny atoms composing the metal apparently turn or twist under the action of a magnetic field and while those of iron turn so as to make the total length greater, those of nickel reverse the action. Turning and twisting against the strong cohesive forces of the metal in both cases, however, causes heat.

Permalloy which neither contracts nor expands and shows very little heat may be pictured as the well-ordered scheme where little groups of iron and nickel atoms cooperate in their movements so that there is no wasted effort. The iron atoms acting in one way slip by the nickel atoms acting in another so that friction is a minimum.

Equipment was designed to measure changes of length in a piece of wire about 4 in. long. One end of the 4-in. section is fixed in position and to the other end a clamp is attached which connects to the short arm of a lever. The long arm of this lever tips a concave mirror as the wire changes its length. Light from an incandescent lamp, after passing through a suitable lens, falls on the mirror at a small angle from the perpendicular and is reflected back to a position somewhat offset from the lamp where a photoelectric cell is mounted.

Between the light source and the mirror is a grating with alternate opaque and transparent lines, each half a millimeter thick. The image of this grating falls on the mirror and is reflected back to an extension of the same grating in front of the photoelectric cell. When the images of the transparent lines are reflected back to another group of transparent lines, full light will fall on the cell. When, on the other hand, they fall on the opaque lines no light will be transmitted. Only a very small movement of the mirror is required to cause the change from full light to no light.

The photoelectric cell gives off a current proportional to the light falling on it, and this current is indicated by a sensitive galvanometer. The galvanometer indication thus serves to divide the width of one bar of the grating into a large number of smaller divisions. As imperceptible temperature change causes expansion sufficient to tilt the mirror, every precaution is taken to keep the temperature of the wire constant. The entire equipment is mounted on a spring suspension so that building vibrations will not affect it.—P. C. Jones in *Iron Trade Review*, Jan. 26, 1928, p. 268.

Kinematographic Studies in Aerodynamics

Particulars Regarding High-Speed Motion-Picture Methods Employed at the Tokyo Aeronautical Research Institute

By ALEXANDER KLEMIN,[1] NEW YORK, N. Y.

QUITE recently Baron C. Shiba, head of the Aeronautical Research Institute of the Tokyo Imperial University, visited the United States and exhibited a wonderful aerodynamic film in which photographs were taken at the rate of 20,000 per second. The distinguished Japanese scientist visited New York University and made a gift of this film which will always be one of the most prized possessions of the School of Aeronautics of the University.

Tokyo University has been for many years carrying on aeronautical research work of the highest value, and its kinematographic studies are a remarkable contribution to science.

Early Experiments in Momentary Photography

In September, 1924, a first report was issued by Messrs. Terazawa, Yamazaki, and Akishino of the Institute. A small open jet wind channel was used, as shown in Figs. 1 and 2, 30 × 30 cm. at the working section, with good velocity distribution up to 40 meters per second. In these two diagrams W is the wind channel, O the disturbing aerodynamic body round

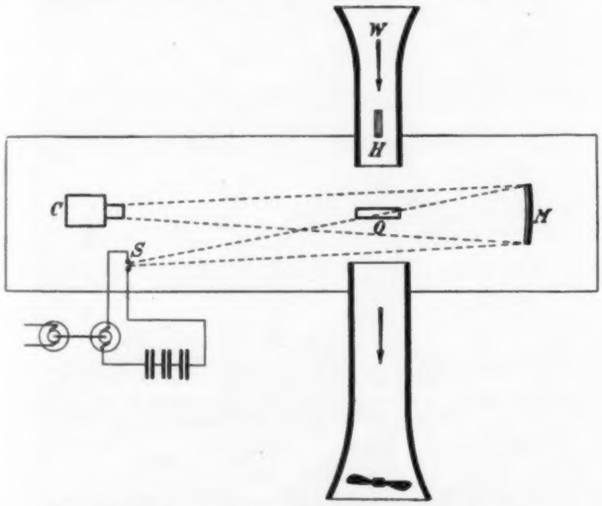

Fig. 1 Striae Method of Momentary Photography

which the flow is to be studied, S the light source, M a concave mirror, C the photographic camera, P the photographic plate, and H a heater.

The heater is made of thin manganin wire stretched on a mica plate and capable of carrying an electric current of 10 to 30 amperes. It was thought at first that the electric heater would disturb the air flow, but by placing it at a certain position and adjusting the strength of the current flow, disturbance was eliminated.

Two photographic methods were employed:

1 The "striae" method, in which a concave mirror of 7 meters radius and 15 inches in aperture was used. The light source was an electric spark, between two aluminum ribbons, nearly 1 cm. apart, which were pressed between two pieces of hard stone.

2 The "shadow" method as illustrated in Fig. 2, in which the light source was an electric spark between two platinum wires of about 1 mm. thickness enclosed in an ebonite rod. One electrode was inserted in a side hole of the rod, and another, provided with an adjusting screw at one end, was put in the central channel of the rod. By connecting these to an electric machine an approximate point source of light was obtained.

These methods of photography are fairly readily explainable by the simple principles of light refraction. If a series of rays from

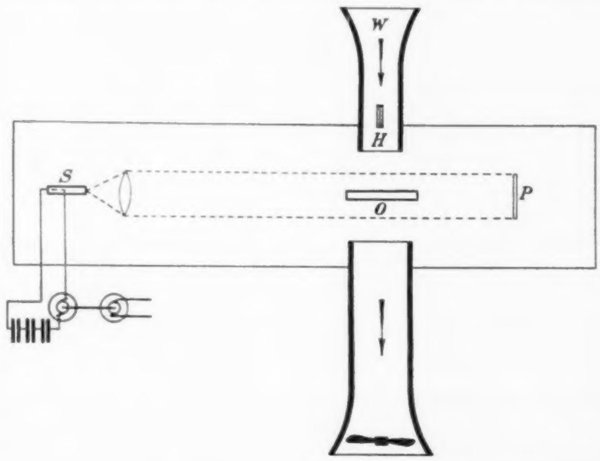

Fig. 2 Shadow Method of Momentary Photography

a point source strike a cylinder having a smaller refractive index than the surrounding medium, a ray lying along a diameter passes on without deviation. Any other ray is bent outward. There is formed a bright spot or band, with a shadow on either side.

Thus Captain Lafay, writing in *La Technique Aeronautique*, 1911, states that when exploring air flow by the use of a jet of acetylene (which has a density close to that of air but a different index of refraction) he saw an image on a screen in the form of a brilliant line surrounded by two dark lines. In the Tokyo experiments the heated air had a lesser density than the surrounding air, and therefore a lesser index of refraction, and consequently produced a similar effect. Even if the hot air particles were plane and not cylindrical or spherical, the same effect would be present though not quite to the same extent. The prime essential for these methods would appear to be that the hot air enters the rest of the stream as a series of individual particles, with some cold air particles intervening. If the heated air stream formed a continuous layer, no real images would be formed. Baron Shiba's film seems to indicate that the heated air does indeed appear as a series of individual particles. Lafay says, "La continuité initiale n'est qu' apparente et le jet d'acétylene se trouve brisé, dés sa sortie, comme la fumée d'une cheminée par le souffle de l'ouragan."

The choice between the "striae" and the "shadow" methods is

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Presented at the Aeronautic Session of the Annual Meeting of The American Society of Mechanical Engineers, Washington, D. C., December 8, 1927.

one solely of technique. The author's supposition is that with the striae method, where rays diverge from a point source, the refraction effects will on the whole be more marked than with the shadow method where the rays are parallel.

The majority of the early plates secured by this method were destroyed by fire following on the great earthquake. Four of the remaining plates, all obtained by the shadow method at 16.6 meters per second, are shown in report No. 8 (Sept., 1924) of the Institute.

Early Experiments in Kinematography

In the experiments mentioned above Captain Lafay found that an exposure of one-thousandth of a second gave for a wing at a small angle of incidence an appearance of smooth flow. An instantaneous photograph gave a flow which was of the same general character, but with the individual particles of the gas indicated in a highly disturbed condition. This demonstrated clearly the necessity of extremely short exposures. At the same time, kinematographic studies have an evident advantage where periodic eddies are to be studied, since the flow is then

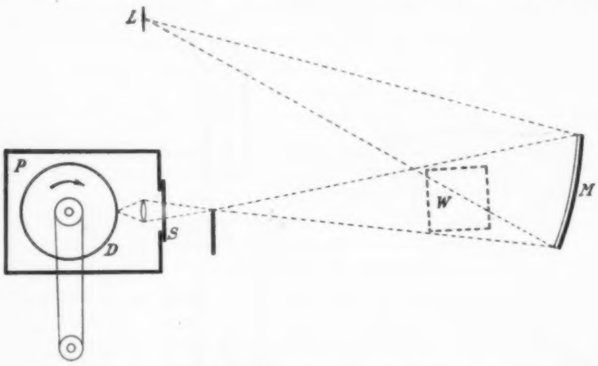


Fig. 3 Early Kinematographic Apparatus

unsteady at given points of the stream, even if the general character of the flow is steady as determined by dynamic force measurements. Kinematographic methods are evidently of superior interest to those of momentary photography.

The Tokyo investigators soon found that the usual shutter method of kinematography could not be adopted as the time of exposure was too long for the pictures obtained to be clear. Accordingly it was decided to use the striae method with periodic sparks of short duration as the light source. The periodic spark had to be of (*a*) regular interval and (*b*) of constant intensity. Successful results were obtained by the use of a high-frequency generator, giving a light source of regular intervals of about $^1/_{950}$ to $^1/_{1200}$ second. The frequency of the generator could be varied from 480 to 610 cycles by changing the speed of the d.c. motor. An ideal set of sparks was obtained mainly by changing the resistance of the primary circuit of the transformer and the capacities in the secondary circuit.

In Fig. 3, *W* is the mouth of the wind channel, where the object to be photographed was placed, *M* the concave mirror, *L* the light source, and *P* the photographic apparatus. The

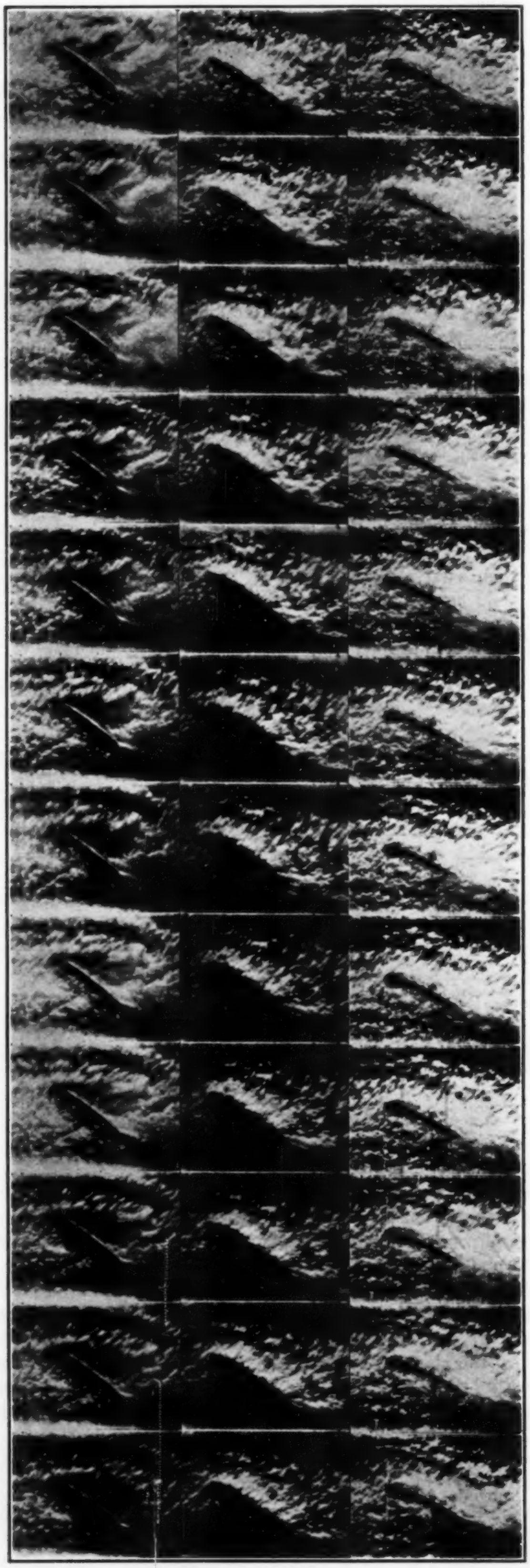


Fig. 4 Fig. 5 Fig. 6

Fig. 4 R.A.F. 15 Wing at 29-Deg. Angle of Attack
(Air speed, 11 m. per sec.; 2100 pictures per sec.)

Fig. 5 A Modified R.A.F. 15 Wing at 29-Deg. Angle of Attack with Front Slot Open
(Air speed, 11 m. per sec.; 2100 pictures per sec.)

Fig. 6 Waldo Wing with Flexible Flaps on Upper Surface at 20-Deg. Angle of Attack
(Air speed, 11 m. per sec.; 2100 pictures per sec.)

last consisted of a shutter S and a wooden drum D round which the film was wrapped and which was driven by a synchronous motor. The shutter is only used as a means of economizing film, being opened at the beginning of an experiment and closed at its end.

A few examples of the pictures taken by this machine were not destroyed by the fire and are reproduced in report No. 8 of the Institute (Sept., 1924). The velocity of the air current was 14 to 15 meters per second, and the number of pictures 1000 to 1200 per second.

High-Speed Kinematography

Not satisfied with the high-speed photographs at the rate of 1200 per second, the staff of the Tokyo Institute developed an entirely new method of photography in which the striae method is again evidently employed, but with a constant source of light and a rotating series of mirror-like surfaces. These are constituted by 120 polygonal, highly polished facets of a thin steel disk similar to a turbine disk. The disk was very finely balanced and capable of running at high speeds. The image to be photographed is reflected by these polygonal surfaces on a cylinder, which by mechanical means is very accurately synchronized in its speed of rotation with the rotary disk. The cylinder is at the same time moved slowly along its axis, so that new portion of the film is continually presented to the image reflected from the narrow, small steel mirrors and a film in the form of very narrow spirals is obtained. The narrow spirals are very carefully cut to give one continuous long film. After development, the film is enlarged to the ordinary film size used in moving pictures. This enlargement necessitated a special mechanical arrangement.

The film as presented by Baron Shiba includes: flow around a R.A.F. 15 airfoil at 29 deg. incidence; a modified R.A.F. 15 airfoil with a Handley Page slot at 29 deg. incidence; a cylinder with air sucked away to smooth out the flow; a Baumann wing in which is found a peculiar double passage or slot at the rear; the Waldo wing with flaps; the tip of an airscrew under static conditions; the tips of two airscrews in tandem; an autogiro; and a vacuum bulb shattered by a bullet.

The wind speed was generally 11 meters per second, with exposures at the rate of either 2100 or 3000 per second. Only in the case of the shattered vacuum bulb was the rate of exposure raised to 20,000 per second.

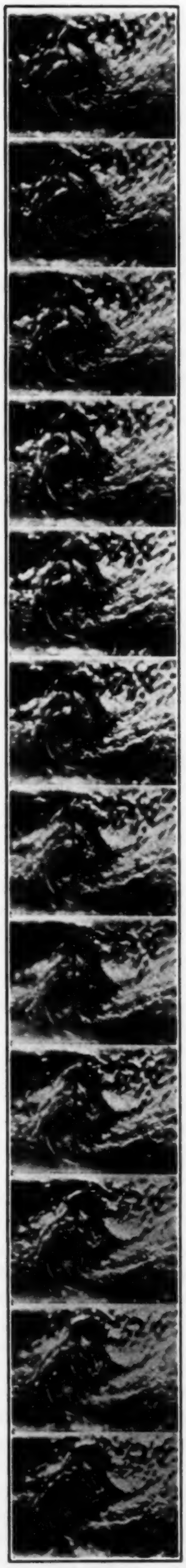
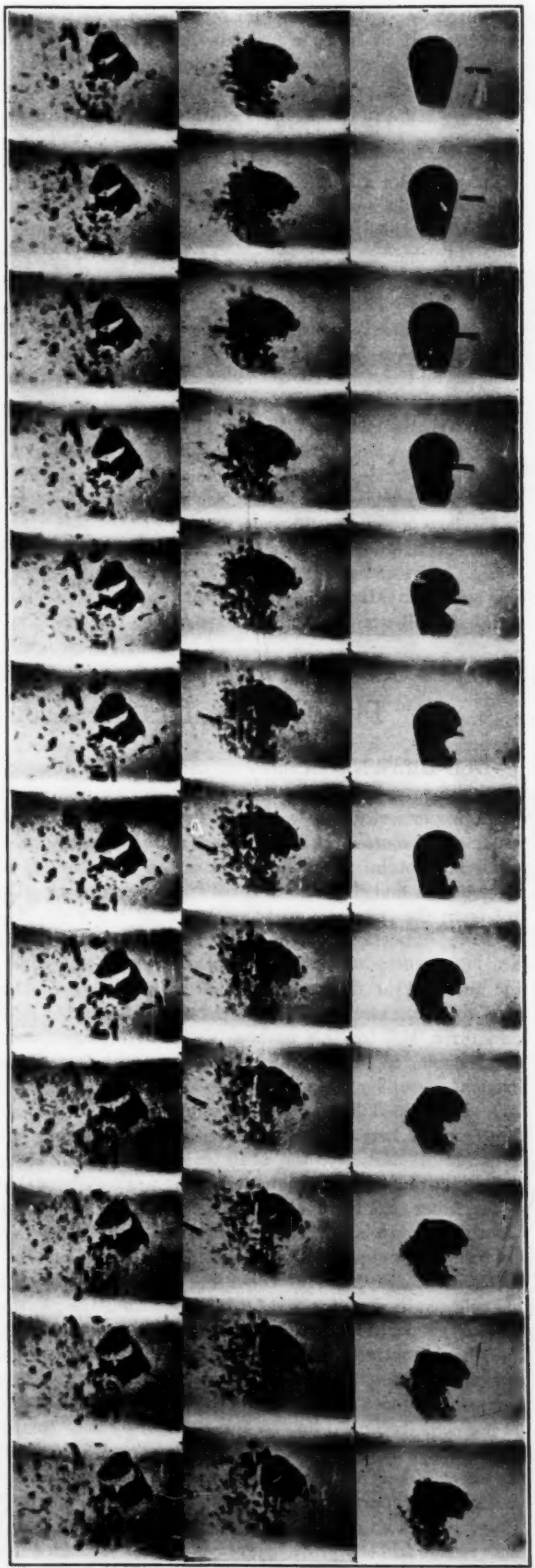


Fig. 7

Fig. 7 The Savonius Rotor, Air Flowing from Left to Right
(Rotor speed, 10 rev. per sec.; air speed, 8 m. per sec.; 2100 pictures per sec.)



(c) (b) (a)

Fig. 8

Fig. 8 Vacuum Bulb Shattered by Bullet —3000 Pictures per Second
[(a) Bullet entering bulb; (b) bullet leaving bulb; (c) bulb shattering after bullet has passed through it.]

The photographs of the film reproduced here would seem to indicate that even when the flow is streamline the individual particles are in a disturbed condition (as previously found by Lafay), but the probability is that the introduction of the warm air is in itself a cause of local disturbance.

Photographs of Parts of the Film

Fig. 4 shows a R.A.F. 15 wing, at 29 deg. angle of attack, air speed of 11 meters per second, filmed at 2100 exposures per second. No definite vortices or eddies are seen, but it is quite clear that the flow has torn away entirely from the upper surface of the airfoil.

Fig. 5 is a modified R.A.F. 15 provided with a front Handley Page slot, tested under the same conditions as the unslotted wing. There is no detachment of flow at all from the upper surface, and the picture provides another proof of the power of the slot.

Fig. 6 shows a wing developed by Professor Waldo of the Tokyo Institute in which the upper surface is provided with flaps which lift up and occupy a position normal to the air flow at high angles of incidence. At 20 deg. angle of attack, no detachment of the flow is visible. Baron Shiba states that this wing can be made to give quite high values of lift.

Fig. 7 illustrates the Savonius rotor, previously discussed by the author in Mechanical Engineering.[2] The Savonius rotor is a windmill which will operate whatever the direction of the wind may be. The rotor shown is revolving at 10 revolutions per second in a wind of 8 meters per second, and is being filmed at the rate of 2100 exposures per second. The rapidity of exposure is well illustrated by the fact that the axis of the rotor scarcely appears to change its position in the twelve exposures, in which the air is flowing from left to right. The air seems to enter the scoops both at top and bottom, and then to lag behind.

An Instrument of Value

It is quite clear that these new methods should be of great value in aerodynamic investigation, and the apparatus is conceivably of much utility in other scientific fields. The striae method of photography has been applied to ballistics since 1881, and there is no reason why the new apparatus should not be employed for the extension of such work. There are probably many other scientific and industrial fields where the apparatus could be employed—for the study of vibration, for example, in high-speed machinery.

References

Physical Optics, Robert W. Wood.

La Photographie du Vent, Captain Lafay, *Technique Aéronautique*, 1911.

Photography at High Velocities, W. A. Hyde, *Science Conspectus*, vol. vi, no. 5, 1926.

Elektrische Methoden der Moment Photographie, B. Glatzel (Vieweg).

[2] November, 1925, p. 911.

The Effect of Heat Treatment on Cold-Drawn Steel Tubes

COLD-DRAWN steel tubes are used to a very large extent in modern machines and structures, and the investigation of their properties and how they are affected by heat treatment becomes a matter of very considerable importance. Boiler tubes are not infrequently "overstrained" in order to increase their length and to make it possible to re-use them after being cut from the tube plate. In cycles of all kinds the steel tube forms an important part of the structure. To braze the tubes, heating of them at the joints is necessary, and the condition of the material in this neighborhood is modified. Cold-worked steel tubes are also used to a very considerable extent in airplane structures, and for this purpose the heat-treatment results are of particular interest. There seems no doubt that the changes brought about by suitable heat treatment have a very marked effect upon the failing loads of tubes, used as not very long struts; and for very long struts, in which the failure depends upon the modulus of elasticity, the heat teatment is again of value.

Results of experiments made by the author show that cold-drawn tubes after the final pass have a low limit of proportionality but the strength is much higher than that of normalized material. Up to a percentage reduction of from 25 per cent to 30 per cent, the statical properties of the tubes are increased. Annealing the tubes at various temperature changes the strength, the maximum strength in tension and in compression being obtained after heat treatment at about 350 to 400 deg. cent. The limit of proportionality of cold-drawn steel tubes in compression may be increased more than 300 per cent and that of tubes in tension 50 per cent (reckoned on the lower value) by heat treatment at temperatures between 360 and 480 deg. cent. After 480 deg. the effect of heat treatment is to cause a very rapid lowering of the limit of proportionality, the ultimate strength, and the fatigue range. The limit of proportionality, the yield stress, and the ultimate tensile and compressive stresses all pass through a minimum after annealing at a temperature between 650 and 750 deg. cent., depending upon the carbon content of the tubes. At an annealing temperature above the normalizing temperature all the properties of the tubes increase, the increase being more marked in those tubes that were annealed below the normalizing temperature before the last pass than in those heat treated above the normalizing temperature before the last pass.

The modulus of elasticity of cold-drawn steel tubes in compression is raised by heat treatment. The change is not more than from 5 to 10 per cent, and the experimental points do not lie closely to the mean curve, but for all sets of tubes there seems no doubt that the modulus of elasticity in the cold-worked state is lower than after heat treatment at from 350 to 480 deg. cent., depending on the carbon content. The modulus of rigidity, as obtained from bending tests, is more uniform; the same is true of brass tests. The modulus of rigidity, as obtained from torsion tests, is also affected by heat treatment and approximately reaches its maximum value after annealing at 400 deg. cent.

The density of cold-worked material is less than the material after heat treatment. The cold-worked steel behaves peculiarly under repetition stresses in that, although a very large number of repetitions of stress, at a high range of stress, can be run, the stress-repetitions curve is continuously falling up to 35,480,000 repetitions, and the falling apparently continues. Interpolating from the data of the paper, it would appear that a 0.35 per cent cold-worked tube may run 1000 million repetitions at a range of stress of 10 tons per sq. in. and 10 million repetitions at a range of stress of 15.3 tons per sq. in. Tubes heat treated after cold drawing at temperatures from 300 to 420 deg. cent. give much higher values. The effect of heat treatment on cold-worked tubes, normalized before the last pass, is to raise nearly all the properties, as compared with the cold-worked tubes, as the temperature of annealing is increased from 100 to 500 deg. cent.—Prof. F. C. Lea in *Engineering*, Dec. 23 and 30, 1927, pp. 797–800 and 831–834.

Viscosity of Lubricants Under Pressure

An Experimental Determination of the Combined Effects of High Pressures and Temperatures, Using the Ball-and-Slanted-Tube Type of Viscometer

By MAYO D. HERSEY,[1] WASHINGTON, D. C., and HENRY SHORE,[2] NEW YORK, N. Y.

The five oils selected for this investigation are believed to be typical of the better-known classes of animal, vegetable, paraffin-base, naphthene-base, and blended oils. The maximum pressures and temperatures reached were respectively about 4000 kg. per sq. cm. (57,000 lb. per sq. in.) and 140 deg. cent. (284 deg. fahr.). Lard oil solidifies abruptly on passing through a critical pressure which, at 22 deg. cent. (71.6 deg. fahr.), is about equal to 1550 kg. per sq. cm. (22,000 lb. per sq. in.). The paraffin-base oil shows a somewhat similar effect. For all of the oils tested except, notably, lard oil it was found that the temperature coefficient of viscosity is considerably increased under moderately high pressures. These and other facts brought out in the paper may have numerous applications in future lubrication research, and have been thought by the Special Research Committee on Lubrication to be of particular interest in the study of oiliness phenomena.

Introduction

When two metallic surfaces that are separated by a thin film of lubricant are in relative motion under any appreciable load, it is evident, if the surfaces are not absolutely smooth, that there must be certain points (near the high spots) where the local pressure in the film is very much greater than the mean pressure over the entire area. Even if the surfaces could be considered absolutely smooth, a variable pressure distribution would be expected if the surfaces depart in the slightest degree from absolute parallelism, and in such a pressure distribution the maximum pressure can be many times greater than the mean pressure.[3]

These conditions of high local pressures in the film seem likely to be of special importance (*a*) when operating under heavy loads per unit area as in gear-teeth or cutting-tool lubrication; and (*b*) when the bearing surfaces are inadequately lubricated, whether due to an insufficient supply of the lubricant, to an insufficient speed for maintaining a thick film, or to any other circumstance.

In fact, whenever the bearing surfaces show signs of rubbing or abrasion it is possible that stresses in excess of the yield point of the metal were present in the lubricating film; and as a first approximation these stresses may be assumed to have the same influence on the properties of the lubricant as a uniform hydrostatic pressure, although if closely examined it might be found that the stress system in the film is not strictly hydrostatic.

The foregoing brief statements are offered merely as an indication of some of the conditions under which very high pressures may exist in lubricating films. The necessity for investigating the properties of lubricants under high pressure will therefore be evident.

Of all the properties of lubricants that may be significant, viscosity plays the leading role, because of its relation to friction. This relationship follows directly from the usual physical definition of viscosity (ratio of shearing stress to rate of shear—meaning by rate of shear the same thing as velocity divided by film thickness at any given point). Practically speaking, then, viscosity is merely another name for the frictional resistance per unit area exerted by the oil film against one of the bearing surfaces, per unit rate of shear.

From this it will be clear that the determination of the viscosity of lubricants as a function of pressure is a necessary preliminary step before any one can hope to predict the performance of bearings theoretically except under conditions favoring the formation of relatively thick films. It is likewise a necessary step, or may prove to be a valuable aid in the interpretation of oiliness experiments—i.e., experiments conducted for the purpose of demonstrating differences in friction due to the use of two or more oils having the same viscosity as determined at the true working temperature of the film but under atmospheric pressure.

There are also problems relating to high-pressure lubricating systems, Diesel-engine fuel injection, hydraulic-press operation, metal-drawing processes, and the like where a knowledge of the viscosity of oils up to a moderately high pressure would be desirable. In general, the need for data on viscosity in relation to pressure is analogous to the need for data on viscosity in relation to temperature, and the ultimate state of knowledge to be sought for is one in which the necessary tables and charts showing viscosity as a function of pressure and temperature are as readily available as the more familiar steam tables and charts.

Recognizing these facts, the Special Research Committee on Lubrication at its first meeting (December 8, 1915) considered different methods by which the viscosity of lubricants could conveniently be measured under high pressure and recommended for our first experiments the ball-and-slanted-tube type or rolling-ball viscometer, previously invented and described by A. E. Flowers.[4]

The work was begun immediately at Harvard University under supervision of P. W. Bridgman. Our heartiest thanks are expressed to Professor Bridgman and to the Director of the Jefferson Physical Laboratory, Prof. Theodore Lyman, for their personal interest and aid as well as for the laboratory facilities offered.

Progress reports[5] have been published at intervals and the

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[1] Formerly Associate Professor of Properties of Matter, Massachusetts Institute of Technology. Mem. A.S.M.E.

[2] Research Engineer, Radio Corporation of America; formerly Research Assistant for The American Society of Mechanical Engineers at the Massachusetts Institute of Technology.

[3] Howarth, H. A. S., A Graphical Analysis of Journal-Bearing Lubrication (1923–1925), reprinted by the A.S.M.E., 29 West 39th St., New York, N. Y.

For presentation at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers. All papers are subject to revision. Offered as a contribution from the Massachusetts Institute of Technology and the Jefferson Physical Laboratory of Harvard University. Acknowledgment is made to the U. S. Bureau of Standards for cooperation and assistance, particularly during 1916 and 1920, and to the U. S. Bureau of Mines for laboratory facilities at the Pittsburgh Experiment Station at intervals during the year 1924–1925.

[4] Flowers, A. E., Viscosity Measurement and a New Form of Viscosimeter. Proc. Am.Soc.Test.Matls., vol. 14 (1914), p. 565.

[5] Hersey, M. D., Theory of the Torsion and Rolling-Ball Viscosimeters, and the Effect of Pressure on Viscosity. *Jl. Wash. Acad. Sci.*, vol. 6 (1916), pp. 525–530. Report of Research Sub-Committee on Lubrication, A.S.M.E., Mechanical Engineering, vol. 41 (1919), p. 537; Second Report, Mechanical Engineering, vol. 43 (1921), pp. 1269–1272; Third Report, Mechanical Engineering, vol. 45 (1923), p. 315; reprinted together with the First Report under the title, Oiliness of Lubricating Oils and Viscosity of Lubricating Oils at High Pressures.

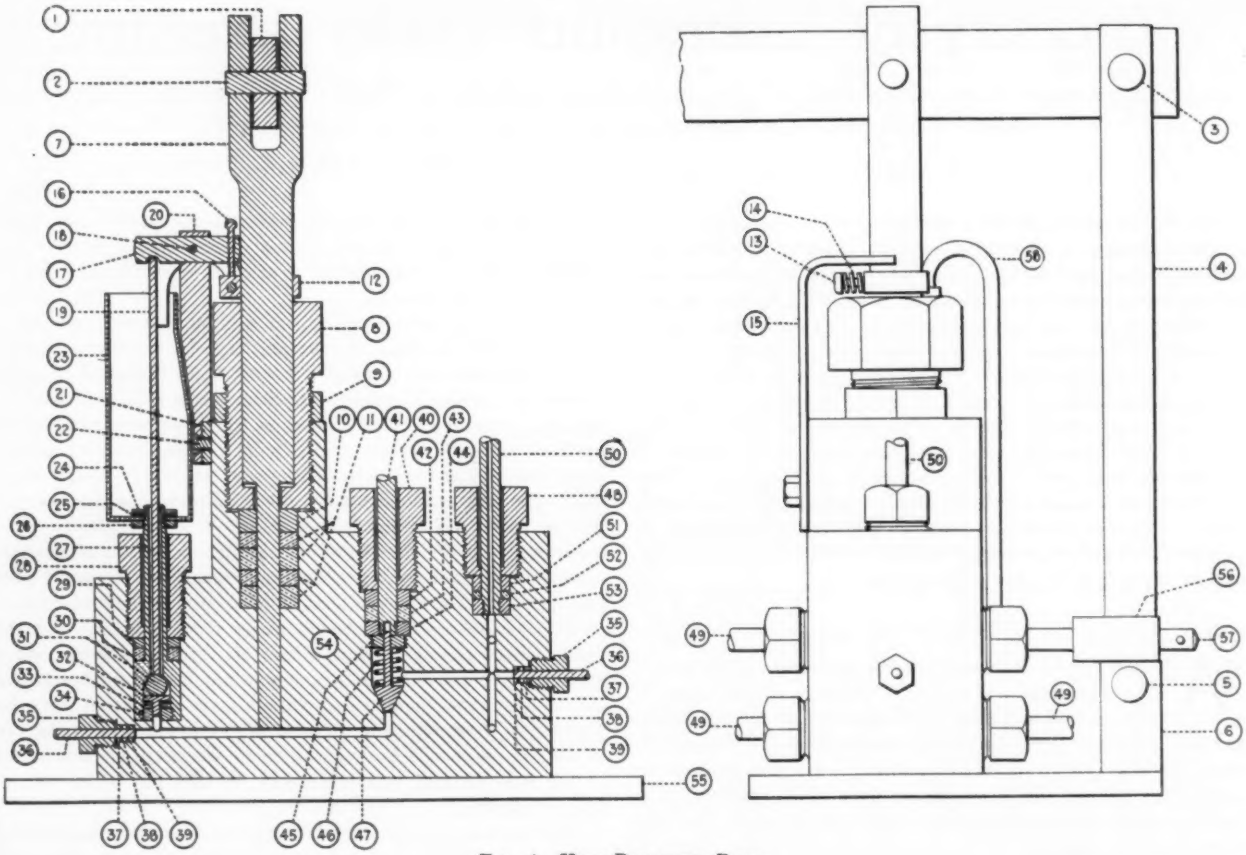

Fig. 1 High-Pressure Pump

Operating Mechanism	1	Handle
	2	Pin Conn. Handle to Piston
	3	Pin Conn. Handle to Fulcrum Link
	4	Fulcrum Link
	5	Pin Conn.-Ful. Link to Base Conn.
	6	Fulcrum Conn. to Base
Piston and Parts	7	Piston
	8	Piston Bushing
	9	Bushing Locknut
	10	Steel Washer
	11	Leather Washers
Inlet-Valve Operating Mechanism	12	Sliding Collar
	13	Adjusting Screw
	14	Spring
	15	Collar Stop
	16	Adjusting Screw
	17	Rocker Arm
	18	Rocker-Arm Pin
	19	Inlet-Valve Operating Rod
	20	Rocker-Arm Support
	21	Support Attachment to Body
	22	Screw
Reservoir and Parts	23	Reservoir
	24	Nut
	25	Rubber Washer
	26	Locknut
Inlet Valve and Parts	27	Inlet-Valve Housing
	28	Inlet-Valve Bushing
	29	Steel Washer
	30	Rubber Washer
	31	Inlet-Valve Ball
	32	Plunger
	33	Spring
	34	Plunger Support
Clean Out and Drain Plugs	35	Drain-Hole Bushing
	36	Rod or Plug
	37	Steel Washer
	38	Rubber Washer
	39	Threaded Washer
Outlet Valve and Parts	40	Outlet-Valve Bushing
	41	Rod or Plug
	42	Steel Washer
	43	Rubber Washer
	44	Threaded Washer
	45	Outlet-Valve Support
	46	Outlet-Valve Spring
	47	OutletValve
Outlet Parts	48	Outlet Bushing
	49	Outlet Plug
	50	Gage Conn. Tubing
	51	Steel Washer
	52	Rubber Washer
	53	Threaded Washer
Body and Base	54	Pump Body
	55	Pump Base
Relief Mechanism	56	Relief-Valve Body
	57	Relief-Valve and Handle
	58	Drip-Return Tubing

same problem has also been investigated by J. H. Hyde at the National Physical Laboratory with significant results.[6]

The work of the National Physical Laboratory was the first to demonstrate the generalization[7] that the viscosities of fixed oils taken as a class (including animal and vegetable oils) are relatively less influenced by pressure than the viscosities of mineral oils. For a time this discovery acted as a deterrent against further development of the thought that the superior oiliness[8] of the fixed oils (notably lard oil) might be attributed in some measure to an increased viscosity due to very high local pressures in the film. It has been found, however, that the proposition that mineral oils have greater pressure coefficients than fixed oils no longer holds true beyond a moderate limiting pressure of the order of 1500 kg. per sq. cm. (roughly 20,000 lb. per sq. in.). At about this pressure, certain oils (notably lard oil) when at ordinary room temperature show very abrupt indications of solidification.

Whether the oils that exhibit this effect freeze hard and solid as a whole, or separate out solidified ingredients, or merely

[6] Hyde, J. H., On the Viscosities and Compressibilities of Liquids at High Pressures. Proc. Roy.Soc.A., vol. 97 (1920), pp. 240–259. See also Appendixes 7, 8, 9, *Report of the Lubricants and Lubrication Inquiry Committee.* Dept. Sci. Ind. Res., London, 1920, pp. 80–90.

[7] Hyde's conclusion serves as an interesting confirmation of the observations reported in our first publication (1916), according to which the pressure coefficient of viscosity for lard oil over a moderate range of pressure was found to be only 0.0023 per kg. per sq. cm., as against 0.0032 for a mineral machine oil having approximately the same viscosity under atmospheric conditions.

[8] Oiliness has been defined by W. H. Herschel as the property that causes a difference in the friction when two lubricants of the same viscosity at the temperature of the oil film are used under identical conditions. (From p. 6, preprint of paper on Viscosity and Friction, presented at the Annual Meeting, Jan. 10–13, 1922, of the S.A.E., 29 W. 39th St., New York, N. Y.)

separate out soft solids of a plastic consistency remains for further research to determine. The effects of high pressure are presumably similar to those caused by cooling to a low temperature at atmospheric pressure.

In any event the observed facts are such as to direct attention once more to the possibility that the superior oiliness of certain oils can be accounted for by an intensified viscosity, as was first suggested by Professor Kingsbury.[9]

Future research on the properties of lubricants under high pressure in continuation of the present work might profitably include not only a general extension of the pressure and temperature limits, but also some endeavor to measure the viscosity and consistency of the adsorbed film within the region of attraction of the surface molecules of the metal.

High-Pressure Equipment

The methods used in the present experiments for producing and measuring high pressures are due to Prof. P. W. Bridgman and have already been described elsewhere[10] except so far as modified for the purpose in hand.

Pump and Intensifier

The starting point of high-pressure experiments is the hand pump. In our earlier work a commercial type of pump was used, but as the ball valves clogged frequently and could not easily be cleaned, a new pump was designed similar to those constructed by Professor Bridgman for his own use. (Fig. 1.) For assistance in the pump design and other work at M.I.T., acknowledgment is made to C. W. Staples.

An essential feature of this type of pump is the parallelogram movement for forcing open the inlet valve whenever the piston moves up, together with helical springs for holding both valves tightly against their seats when they are supposed to be closed.

The leather washers surrounding the piston are treated by heating in pure mutton tallow for several hours at about 125 deg. cent. under a partial vacuum, so as to soften the leather and drive out all moisture. Care must be taken that the tip end of the piston does not tear off minute shreds of leather. These solid particles and similar particles from the rubber packing used in the various connections are liable to cause clogging of valves. Frequent dismantling and cleaning of the pump is worth while, otherwise it may start to clog in the middle of a series of observations after a moderately high pressure has successfully been reached.

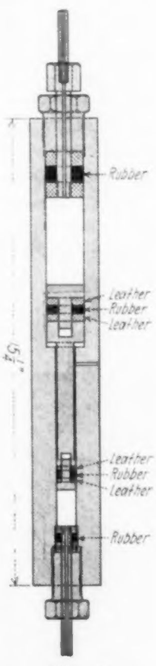

FIG. 2 INTENSIFIER

The piston shown in Fig. 1 has a working diameter of $^3/_8$ in. and serves to produce a pressure of about 1200 kg. per sq. cm. with one man pushing down on the end of the long handle. A new piston more recently constructed has a working diameter of $^1/_4$ in. This enables one man to carry the pressure up well above 2500 kg. per sq. cm. (or to about 40,000 lb. per sq. in.), but it is not usually necessary to push it to the limit, as a small hydrostatic press or intensifier can be used for multiplying the pressures delivered by the pump.

Fig. 2 shows an assembly view of the intensifier. The outer cylinder is made of chrome-vanadium steel, type D, annealed. The piston, composed of three pieces, is of high-carbon tool steel, hardened and ground to an accurate sliding fit.

The piston tends to buckle and bind after a time, causing undue friction which reduces the multiplying power. This condition can be temporarily relieved by straightening and grinding but requires occasional replacement of parts, otherwise the piston may jam so badly that it will be difficult to drive it back into position for another stroke. The multiplying power

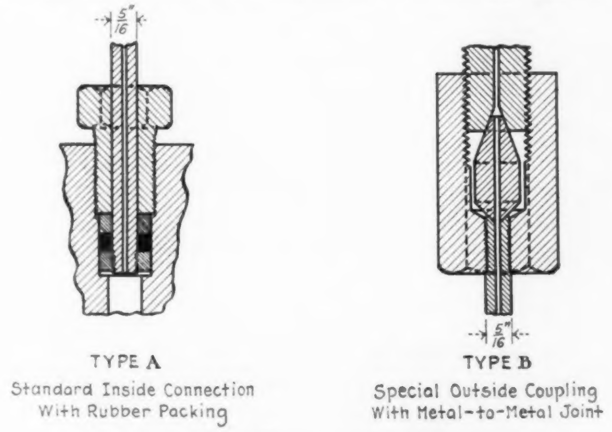

FIG. 3 HIGH-PRESSURE CONNECTIONS

of this intensifier is a little less than 4, which would be the theoretical limit for the present piston areas when the friction is negligible.

Leakproof Connections

Two forms of high-pressure fittings recommended by Professor Bridgman and successfully used throughout our work are shown by Fig. 3. Type A is the standard leakproof form with rubber packing, same as shown in Fig. 1, while Type B was used for joining a Bourdon-tube pressure gage to the $^5/_{16}$-in. Shelby steel tubing leading out of the pump. The small double cone of hardened steel provides a metal-to-metal contact which can be tightened by means of right-and-left threads on the coupling nut, or the nut can be brazed to one of the pipes.

Pressure Measurements

Bourdon-tube pressure gages of commercial type were available for use at moderate pressures, one graduated to 25,000 and the other to 50,000 lb. per sq. in. One of these gages is generally connected directly to the pump and used to read the pressure on the low-pressure side of the intensifier. The 25,000-lb. gage developed leaks on several occasions, but has always been satisfactorily repaired. The 50,000-lb. gage began to leak in the bronze fittings at both ends of the Bourdon tube or spring as soon as it was held for any length of time at pressures exceeding 35,000 lb. per sq. in. Brazing could not be resorted to as it would soften the spring. Various solder compositions harder than normal were tried and served to remedy the trouble temporarily, but never permanently. Therefore at the suggestion of Professor Bridgman the standard fittings of Type A, Fig. 3, were applied, after drilling a hole in each extremity of the spring $^5/_{16}$ in. in diameter to take the steel and rubber washers. These washers were mounted on a tube of alloy steel (chrome-vanadium, type D) of 0.10 in. outside diameter and 0.04 in. inside diameter

[9] Kingsbury, A., A New Oil-Testing Machine and Some of Its Results. Trans. A.S.M.E., vol. 24 (1903), pp. 143–160 (Note par. 3, p. 144).

[10] Bridgman, P. W., Measurement of High Hydrostatic Pressure, Proc. Am.Acad.Arts.Sci., vol. 47 (1911), pp. 321–343. Technique of High-Pressure Experimenting, Proc. Am.Acad.Arts.Sci., vol. 49 (1914), pp. 627–643. Properties of Matter Under High Pressure, MECHANICAL ENGINEERING, vol. 45 (1923), p. 161. The Effect of Pressure on the Viscosity of Forty-Three Pure Liquids, Proc. Am. Acad.Arts.Sci., vol. 61 (1926), pp. 57–99.

at the inlet opening of the spring, and on a solid rod of the same outside diameter at the dead end of the spring where a plug was required.

For measuring actual pressures to which the oil samples in the viscometer were subjected during observations, which would frequently exceed the limit of the commercial type of pressure gage, use was made of the electrical-resistance pressure gage as developed by P. W. Bridgman. According to data published by Professor Bridgman the resistance of manganin wire increases 2.3 per cent for 10,000 kg. per sq. cm. rise of pressure (1.6 per cent for 100,000 lb. per sq. in.), and is practically independent of moderate changes in room temperature. The usual methods of resistance measurement by a Wheatstone or Carey-Foster bridge are capable of very high accuracy, so if the manganin coil is long enough to have a resistance of the order of 100 ohms it will serve as a sensitive and reliable pressure gage.

The coil is wound in the form of a torus of from $^3/_8$ to $^5/_{16}$ in. outside diameter and $^1/_8$ to $^3/_{32}$ in. inside diameter. Silk-insulated wire about 0.1 mm. (approx. 0.005 in.) in diameter is used. The latest coil used in our tests was 11 ft. long and its resistance at atmospheric pressure was about 121 ohms.

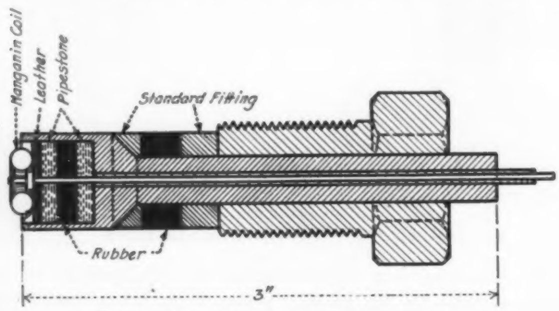

FIG. 4 MANGANIN-COIL PRESSURE GAGE

Prewar stock from Germany was used, of the same original lot calibrated by Professor Bridgman.

One terminal of the coil is grounded to the outside of the steel plug on which it is mounted (Fig. 4); the other is carefully soldered to a stiff central wire or rod situated on the axis of the plug but insulated from it. The soldering of this fine wire requires care lest the insulation be burned off or the wire made brittle so that it afterward breaks easily. The grounded terminal should be soldered in a groove, so as not to be broken off if the end of the plug is forced into contact with other parts.

The seasoning of the coils requires annealing in air for about 24 hours at 140 deg. cent., followed by several cycles of pressure application. A satisfactory test for successful seasoning is the immediate return of resistance to its initial value following release of pressure, after the pressure has been maintained for an hour or more at the maximum amount to be employed.

The calibration constant for the manganin coil was rechecked at the conclusion of our experiments by observing the known transformation pressure[11] from ice I to ice III at an approximate temperature of —23 deg. cent. This pressure is 2120 kg. per sq. cm. (30,100 lb. per sq. in.). Practically perfect agreement with the assumed value of 2.30 per cent for 10,000 kg. per sq. cm. was found.

The electrical resistance measurements were at first made on a Carey-Foster bridge, but later on a simple form of Wheatstone bridge using a drum slide wire. If all arms of the bridge are kept constant except the arm which contains the manganin-coil pressure gage, this arm can be brought back to its original resistance, and the galvanometer balanced, by shifting the contact on the slide wire just enough to compensate. The observed decrease in slide-wire resistance necessary for a balance gives an exact measure of the increase in the resistance of the manganin coil due to pressure. A knowledge of the initial resistance of the manganin coil in ohms together with the percentage increase of resistance of the manganin wire per unit increase or pressure provides all the data necessary for converting the drum readings into kilograms per square centimeter or pounds per square inch, since the relation between drum reading and pressure is linear.

General Arrangement of the High-Pressure Apparatus

The pump, mounted on its framework of heavy iron pipe, with four legs, stands on the floor; the intensifier is fixed to the top of the pump framework in a horizontal position with its low-pressure end connected to one of the pump outlets by a short section of steel tubing. The manganin-coil pressure gage is inserted in one opening of a T, known as the gage block (a rectangular block of mild steel with three openings). The second or left-hand opening of the T is connected to the high-pressure end of the intensifier, while the right-hand opening of the T goes to the viscometer. The gage block is firmly mounted on the top of the pump framework and the connection to the viscometer is made through a 6-ft. length of flexible Shelby steel tubing of $^5/_{16}$ in. outside and $^1/_{16}$ in. inside diameter. By means of a rope passing over a pulley in the ceiling, the far end of the viscometer can be hoisted up to any desired angle, and quickly allowed to fall. The viscometer is so mounted that after striking the floor its axis will remain at the required angle of inclination (normally 15 deg. with the horizontal).

A glycerine-and-water mixture is used for the pump liquid (extending into the low-pressure side of the intensifier), while kerosene is used for transmitting pressure to the manganin-coil gage.

Safety Precautions

It is important to reduce the frequency of accidents not only to avoid personal injury but to prevent loss of oil samples and loss of time due to reassembly and the development of a steady temperature.

As at present designed, the viscometer, intensifier, and other parts are stronger than the Shelby tubing. The latter is practically free from chance of failure other than such as is caused by reduction of strength at the ends where connections are made. If properly connected, the Shelby tubing should hold from 4000 to 5000 kg. per sq. cm. (about 60,000 to 70,000 lb. per sq. in.), but failure has occurred below these pressures and must be provided for.

Such failures take place either by stripping the threads at the very end of the tubing and pulling out from the viscometer connection, or by *pinching off* immediately outside of this connection. The pinching-off effect, which has been described in Professor Bridgman's publications, is due to internal pressure, but has the external appearance of an ordinary tension break in ductile material.

When the Shelby tubing breaks loose from the viscometer for any reason under high pressure, the viscometer, which is suspended from the ceiling, strikes against the wall, the hot oil creates more or less havoc, and the Shelby tubing, if not prevented, whips about violently and will be found buckled into the shape of a letter S. Protection from the whipping and buckling can be obtained by enclosing the Shelby tubing in a large piece of iron pipe open at the ends.

Aside from failure of the Shelby-tubing connection, the principal accident to be guarded against is the blowing out of

[11] Bridgman, P. W. Water in the Liquid and Five Solid Forms. Proc. Am.Acad.Arts.Sci., vol. 47 (1912), pp. 441–558.

plugs and stems, which shoot with the force of a bullet in the direction of the axis of the hole. Protection may be secured by shields suitably placed.

The remedy for blow-outs at moderate pressures is to be found in accurate construction of all fittings, and especially in having the steel washers full-sized (a tight sliding fit) and the rubber washers slightly oversized (rounded out). At the highest pressures, however, blow-outs are to be expected if it is desired to carry the apparatus to its limit.

Besides preventing leaks, another reason for special care in having the steel washers tight and accurately fitted is to prevent the soft rubber from flowing into the clearance space surrounding the steel washers, where at elevated temperatures it forms a bond with the steel. This is so difficult to remove that it makes it almost impossible to drive the fittings out when disconnecting the apparatus.

When oil or any liquid is forced out of a small leak under high pressure it will be very much hotter than it was on the inside, due to fluid friction, and when at all combustible, has been known to ignite upon reaching the air.

Viscometer and Electric Contacts

The principle of the ball-and-slanted-tube type of viscometer,[12] due to A. E. Flowers, was first applied to our problem in the form of a boiler gage glass containing a small steel ball whose movement through the oil sample could be visually observed. These glasses are surprisingly strong, and the one first selected withstood sufficient internal pressure to demonstrate the existence of the pressure effect on the viscosity of lubricating oils. Connection to the high-pressure pump was made through a simple modification of the type A rubber-packing connection (Fig. 3) without requiring any mechanical work to be done on the glass itself.

Later a thin-walled steel tube was employed, using electric contacts to indicate the time of arrival of the ball at the end of the tube. The results up to 500 kg. per sq. cm. (about 7000 lb. per sq. in.) published in 1916 were obtained with that apparatus.

For higher pressures a thick-walled steel cylinder became necessary, therefore one was constructed of chrome-vanadium steel, type D, annealed, as shown in Fig. 5. For assistance in constructing the viscometer, as well as in other work at Cambridge, acknowledgment is made to V. E. Whitman and H. B. Henrickson.

The viscometer cylinder is mounted on a wooden block so as to stand at an angle of 15 deg. with the horizontal, and, as indicated above, it is connected to the stationary parts of the apparatus by a long piece of flexible steel tubing.

The bore of the cylinder is $^{27}/_{64}$ in. in diameter (except for the enlarged openings at the ends) and the straight part of the bore along which the ball travels is $10^3/_{16}$ in. long. The steel ball used is of the commercial type, $^1/_4$ in. in diameter.

The ball makes contact with an insulated rod or spike when it arrives at the lower end of the viscometer after traveling down the 15-deg. incline. Immediately after hitting the spike and coming to a standstill, the ball sinks through the oil film which separates it from the metal wall of the viscometer and thus completes an electric circuit which actuates a relay. The relay operates a signal in response to which the observer presses his stop watch.

Time lag of the observer in responding to the signal is of importance only when testing very fluid samples, and is approximately compensated by the corresponding lag when starting the watch following the thud which is heard when the viscometer and wooden block strike the floor. Time lag due to the oil film under the ball can be reduced by the use of a suitable voltage together with a sufficiently sensitive relay.

The contact plug in the far end of the viscometer is a duplicate of the plug holding the manganin coil (Fig. 4) except for the prolongation of the central terminal or contact spike.

Some difficulty is experienced in providing simultaneously electrical insulation, mechanical strength, freedom from leaks, and endurance of the rubber or other packing materials under the combined action of oil and of heat. At best, the contact plug and other fittings have to be frequently renewed when the temperatures are pushed above 75 or 80 deg. cent. In future work, therefore, at temperatures above 150 deg. cent., it is believed that the type of fittings developed by the Geophysical Laboratory, which are specially intended for high-temperature work, may be found more suitable.

Several modifications of the viscometer are under consideration for future use which might enable us to record the movement of the ball continuously. An attractive feature of the *balance method* suggested for this purpose by Professor Kingsbury some years ago to the Committee is that it does not require any electric-contact plug in the viscometer, thus eliminating some of the difficulties mentioned above. Any method for securing continuous observations will simplify the determination of exceptionally high viscosities, including the determination of the critical pressures at which solidification apparently takes place.

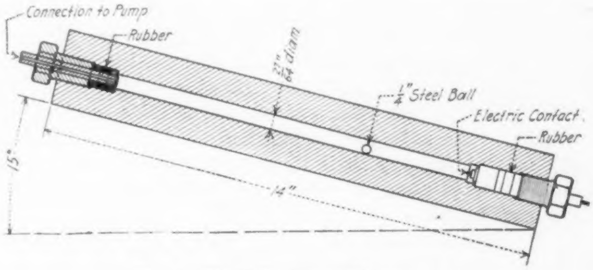

FIG. 5 HIGH-PRESSURE VISCOMETER

For measuring the consistency of samples that have become plastic under high pressure some type of viscometer is preferable in which the rate of shear is uniform at all points, and in which it can be varied at will, since the viscosity of plastic materials (ratio of shearing stress to rate of shear) is not a constant at any fixed pressure and temperature, but normally diminishes with increasing rates of shear.

Heating Coil and Temperature Measurements

The heating coil consists of about 20 ohms of nichrome wire wound around the entire length of the viscometer, with the spacing closer near the two ends to insure uniform temperature. The coil is insulated from the viscometer by asbestos paper; several layers of asbestos are tightly wrapped around the outside and the whole encased in a zinc sheath with binding posts mounted on the outside. This combination forms a rigid shell or jacket making a snug fit on the viscometer, but which can be slipped on and off.

Current is taken from the 110-volt a.c. line and regulated by a rheostat so as to hold the ammeter constant at any predetermined value of the current after approximate temperature equilibrium has been reached. Several hours' time is required in order to reach a fairly steady state. The current, I, in amperes needed for maintaining any given temperature elevation Δt (deg. cent.) above room temperature has been found approximately equal to $0.17\sqrt{(\Delta t)}$ for moderate temperature differences.

[12] Flowers, A. E., Proc. Am.Soc.Test.Matls., previously cited.

Copper-constantan thermojunctions are buried in the metal walls of the viscometer, one at each end (not shown by Fig. 5). The two holes were drilled as deep and as close to the interior as seemed practicable, using a very small drill, so that a correct indication of the oil temperature may be obtained when a steady state has been reached. Cold junctions were kept in the usual ice bath. The two couples were calibrated and checked with particular care. The full accuracy available was not utilized in many of the runs as it was found more convenient to obtain the readings of the thermocouples with the aid of a recording potentiometer. This could not be relied upon within ± 0.5 deg. cent., but proved of great assistance in determining whether a steady state had been reached.

Procedure in Taking Observations

Following the completion of a test and in preparation for testing a different sample, the intensifier and viscometer must be uncoupled and both the pump liquid and oil sample removed, and the piston or ram of the intensifier must be pushed back into position for a new stroke. All washers are inspected to make sure the rubber ones have not deteriorated or the steel ones worn loose. After cleaning out the previous oil sample, using carbon tetrachloride, the viscometer is placed vertically in a vise with the electric-contact end at the bottom, and filled with the new sample to be tested. The viscometer must be allowed to remain in this position long enough for any air bubbles to rise to the top, which can be facilitated by warming. It is then filled to the point of overflowing so that when the remaining connections, filled and allowed to drip, are brought down from above to be coupled together, there will be no opportunity for trapping any air in the system. The presence of an air bubble would cause an error in the low-pressure readings by shortening the time of descent of the ball.

After reassembling but before tightening up the connections, readings are taken at atmospheric pressure in order that the zero points of all gages may be checked. After once tightening up, it is difficult, owing to the friction of the ram, to make certain that the pressure has been fully released. The temperature of the viscometer should be checked with particular care at this time and a series of observations may now be taken to establish the viscometer reading for the viscosity of the sample under standard atmospheric conditions.

When pressure is first applied to the viscometer, it should be done by quick strokes of the pump in order to close up the packing at every point, for unless the washers are tight to begin with, the automatic leakproof principle does not apply. After raising the pressure to approximately the desired amount, some time should be allowed for the heat of compression to be carried off before making the final adjustment of pressure and taking the final readings.

Owing to the time required for reaching a steady state of temperature, it is best to make a complete cycle of pressure changes at each temperature before going on to another temperature; in other words, the original observations are to be taken along isothermal curves. Isopiestics can afterward be determined graphically.

Reduction of Observations to Standard Conditions

Corrections must be applied for departure from the standard angle of inclination (15 deg. with horizontal), for departure from the standard path or distance ball is free to roll (9.88 in.), for departure from uniform velocity during the first part of the roll time, and for small deviations from the standard temperature adopted for each different isotherm. For convenience the first three were made before converting roll times into viscosities, and the last was made afterward.

Corrections for Initial Path and Angle. When the initial ($p = 0$) path is less than the standard length (9.88 in.) the observed roll time is too short so that a positive correction must be applied. This correction expressed as a percentage of the observed roll time is equal to 100 $(9.88 - P)/P$, where P is the actual initial path. This correction never exceeded 3.3 per cent.

When the angle with the horizontal exceeds 15 deg. the roll time will be too short and the correction to apply is positive. It was found by experiments on glass tubes of the same internal diameter as the viscometer (about 1 cm.) that the rate of change of roll time for 1 deg. change of angle in the neighborhood of 15 deg. was approximately 8.3 per cent. Adopting this value, which has also been confirmed by approximate theoretical calculations, we obtain for the percentage correction 8.3 $(A - 15)$, where A is now the angle in degrees.

On several occasions, owing to alterations in the viscometer, slight variations from the standard angle were found for which approximate corrections have been applied.

Path Correction Under Pressure. Visual observations on the shortening of the rubber washers under pressure agreed reasonably well with estimates based on the elastic constants of rubber as given in published tables. Adopting the mean of the observed values, the corresponding compressibility K can be computed from the formula $K = -(1/v)(dv/dp)$, where v is the volume of three washers at pressure p. Since the cross-section is constant, v can be measured in linear inches. Integrating and setting $v = v_0 = {}^3/_4$ in. when $p = 0$ gives $K = {}^2/_9 \times 10^{-5}$ sq. in. per lb. But $v = v_0 - x = {}^3/_4 - x$, where x is the shortening in inches; and therefore $\log_{10} [0.75/(0.75 - x)] = 2.9\, p/10^6$, where p is measured in pounds per square inch.

The amount of shortening, x, at any pressure p and the corresponding roll-time correction are computed from the above formula. These corrections are negative, and amount to a little over 2 per cent at 4000 kg. per sq. cm.

Velocity Correction. To correct for varying velocity of the ball, and reduce the roll time to the value T which it would have at a constant velocity equal to the so-called "terminal velocity," the formula

$$\frac{\Delta T}{T_0} = 0.21\,(1 - \sqrt{1 - 8/kT_0^2}) \qquad [1]$$

has been derived, where for liquids of specific gravity lying between 0.8 and 1.0, $k = 8.3$ if T_0 is expressed in seconds. In this formula T_0 denotes the observed roll time and ΔT is the correction to be applied (a negative quantity). This correction is less than 0.5 per cent when T_0 is equal to or greater than 5 seconds.

Temperature Correction. The viscosity correction $\Delta\mu/\mu$ for any small deviation Δt from the standard temperature t_s is jointly proportional to the magnitude of the deviation, $(t - t_s)$ or Δt, and to the temperature coefficient of viscosity, $(1/\mu)d\mu/dt$, at the temperature t and pressure p of the observation. The correction $\Delta\mu$ is positive when t is greater than t_s and is computed by the formula

$$\frac{\Delta\mu}{\mu} = -\lambda\,\Delta t \qquad [2]$$

in which λ represents the temperature coefficient, $(1/\mu)\, d\mu/dt$, which is a negative quantity. Therefore, in order to reduce the observed viscosities μ to the standard viscosities μ_s at temperature t_s, an approximate knowledge of the temperature coefficient as a function of pressure and temperature must be available.

For the purpose in hand, this information was readily obtained by plotting a preliminary set of curves based exclusively on those

observations which happened to fall within 0.1 deg. cent. of the exact standard temperatures desired, such as 25 deg. cent., 100 deg. cent., etc.

CALIBRATION OF THE VISCOMETER

The roll time for a given liquid increases approximately in proportion to its absolute viscosity and more nearly so the longer the roll time; i.e., the limiting relation for long roll times can be written

$$\mu = \frac{T}{T_1} \qquad [3]$$

In this equation μ denotes the viscosity in poises and T the corrected roll time in seconds, therefore the proportionality

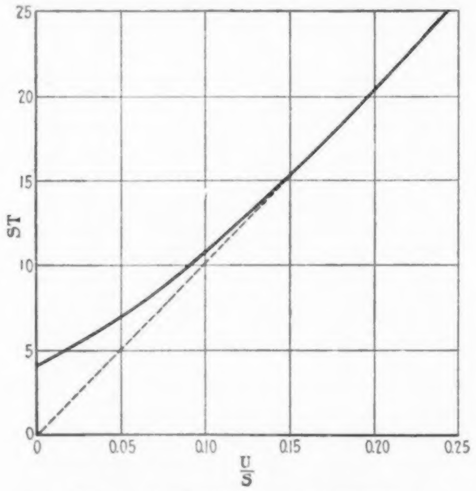

FIG. 6 CALIBRATION OF VISCOMETER

(Enlarged view of lower portion of graph: upper portion continues straight. T = roll time; U = kinematic viscosity; S = function of density.)

constant T_1 represents the roll time in seconds for a viscosity of one poise. The constant T_1 depends on the oil density; for example, when the density is 0.9 gram per cu. cm., T_1 = 14.6 sec.

For short roll times the calibration formula is more complex owing to the occurrence of turbulent motion in the oil sample, as has been demonstrated by observations with glass tubes. Under these conditions the density of the oil plays a more important part than before, so it is necessary to go back to the general relation previously published,[13] which in the particular case of the present viscometer reduces to

$$ST = f\left(\frac{U}{S}\right) \qquad [4]$$

In this equation U denotes the kinematic viscosity μ/ρ (ratio of viscosity to density where μ is the viscosity in poises and ρ the density of the liquid in grams per cubic centimeter); S denotes $\sqrt{(\rho_0/\rho - 1)}$ in which ρ_0 is the density of the steel ball, about 7.9 grams per cu. cm.; and T as before represents the corrected roll time in seconds. The function f is unknown until determined by actual experiment, and this experiment constitutes the calibration of the viscometer.

By the use of a graded series of liquids of known viscosities and densities, the curve shown by Fig. 6 was obtained. From this it appears that Eq. [4] takes the form

$$ST = 102\frac{U}{S} \qquad [5]$$

[13] *Jl. Wash. Acad. Sci.*, vol. 6 (1916), pp. 525–530 (previously cited). See Eq. [5], p. 527.

for long roll times. Solving [5] for the viscosity ($\mu = \rho U$) gives

$$\mu = \left(\frac{7.9 - \rho}{102}\right) T \qquad [6]$$

and this becomes identical with [3] on setting

$$T_1 = \frac{102}{7.9 - \rho} \qquad [7]$$

For converting roll times into viscosity values when ST is less than about 16, i.e., when T is less than about 6 seconds, reference is made to the curve itself.

It remains to express the density ρ as a function of the pressure p and temperature t for the respective oils tested. As we are concerned only with comparatively small changes of density and since these changes have only a relatively slight influence on the result, it is sufficient to use the simple linear relation

$$\rho = \rho_0\left(1 + \frac{p}{E} - \frac{\theta}{A}\right) \qquad [8]$$

In this equation θ denotes the temperature elevation in degrees centigrade above 25 deg. cent., A denotes $1/a$ where a is the mean coefficient of cubical expansion between 25 and 100 deg. cent., E is the bulk modulus of elasticity of the oil, and ρ_0 its density under normal conditions, i.e., when $p = 0$ and $\theta = 0$.

The values used in applying Eq. [8] are shown by Table 1.

TABLE 1 DENSITY COEFFICIENTS FOR LUBRICATING OILS[14]

Lubricant	Normal density, ρ_0, gram per cu. m.	Bulk modulus, E, kg. per sq. cm.	Expansivity reciprocal, A, deg. cent.
Lard oil	0.91	22000	1470
Veedol medium	0.88	23000	1490
Texaco medium	0.92	23000	1520
Mobiloil A	0.93	23000	1670
Castor oil	0.96	24000	1400

The first step in converting a corrected roll-time reading T into viscosity μ is therefore to compute the approximate oil density ρ at the given pressure and temperature by reference to Eq. [8] and Table 1. Afterward, if the roll time is less than 6 sec., proceed as follows: (1) Compute the numerical value of ST, taking $S = \sqrt{[(7.9/\rho) - 1]}$; (2) With this value as ordinate find the corresponding abscissa U/S from Fig. 6; (3) Multiply the latter by ρS and the result is the absolute viscosity μ. When the roll time is greater than 6 sec., as in the actual tests it always was except at very high temperatures, it is sufficient to use Eq. [7] without reference to the curve.

NUMERICAL DATA ON SIX SAMPLES OF OIL

Final results of tests on six representative oil samples are given in Tables 2–7 below, comprising lard oil, Veedol medium, Texaco medium, Mobiloil A, and two samples of castor oil. These are believed to be reasonably typical of the animal oils, paraffin-base, naphthene-base, mixed-base, or blended oils, and vegetable oils, respectively. The first five samples, including castor oil No. 1, were obtained from commercial sources in the locality of Cambridge, Mass., during the year 1920–1921, while castor oil No. 2 was purchased in Pittsburgh, Pa., in 1925.

Logarithms (to base 10) have been tabulated for convenience in plotting. Values preceded by the sign "greater than" (>) signify that the corresponding roll times were so long that the

[14] Derived from published data together with specific-gravity observations on the present samples. Cf. Archbutt and Deeley, Lubricants and Lubrication (1912); Lewkowitsch, J., Chemical Technology and Analysis of Oils, Fats, and Waxes (1915); Hyde, J. H., references previously cited; Herschel, W. H., The Redwood Viscosimeter, Bur. Stds., Technolog. Paper 210, 1922; Kaye, G. W. C. and Laby, T. H., Physical and Chemical Constants (1921).

experiment had to be terminated before the ball reached the end of its path; the apparent viscosity being indefinitely greater than the value recorded. In rare instances the movement of the ball may have been interfered with or electric contact prevented by a particle of foreign matter, but in general the values in question are to be interpreted as indicating a real change in consistency of the oil which may be described as apparent solidification.

TABLE 2 VISCOSITY OF LARD OIL UNDER PRESSURE

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
TESTS 1–26 AT 22 DEG. CENT.							
1	0	0.77	$\bar{1}.89$	14	1080	3.27	0.52
2	0	0.77	$\bar{1}.89$	15	1200	3.85	0.59
3	190	1.07	0.03	16	1320	4.48	0.65
4	330	1.29	0.11	17	1490	6.11	0.79
5	410	1.42	0.15	18	1540	15.6	1.19
6	630	1.88	0.28	19	1560	>242	>2.38
7	780	2.26	0.35	20	0	0.82	$\bar{1}.91$
8	980	2.87	0.46	21	510	1.76	0.25
9	1140	3.52	0.55	22	730	2.36	0.37
10	1350	4.48	0.65	23	990	3.12	0.49
11	20	0.75	$\bar{1}.88$	24	1180	4.30	0.63
12	370	1.26	0.10	25	1360	5.73	0.76
13	1680	> 169	>2.23	26	1780	5.73	0.76
TESTS 27–47 AT 100 DEG. CENT.							
27	450	0.10	$\bar{1}.00$	38	1590	0.29	$\bar{1}.46$
28	880	0.18	$\bar{1}.26$	39	1830	0.35	$\bar{1}.54$
29	1080	0.24	$\bar{1}.38$	40	2180	0.44	$\bar{1}.64$
30	1150	0.26	$\bar{1}.42$	41	2530	0.51	$\bar{1}.71$
31	1080	0.22	$\bar{1}.34$	42	2840	0.62	$\bar{1}.79$
32	1150	0.24	$\bar{1}.38$	43	2900	0.65	$\bar{1}.81$
33	1210	0.24	$\bar{1}.38$	44	3180	0.80	$\bar{1}.90$
34	1610	0.33	$\bar{1}.52$	45	3540	1.07	0.03
35	1630	0.34	$\bar{1}.53$	46	2070	0.42	$\bar{1}.62$
36	1830	0.38	$\bar{1}.58$	47	2290	0.48	$\bar{1}.68$
37	1420	0.25	$\bar{1}.40$	...	....	....	....

TABLE 3 VISCOSITY OF VEEDOL MEDIUM UNDER PRESSURE

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
TESTS 48–90 AT 20 DEG. CENT.							
48	0	1.70	0.23	70	0	1.87	0.27
49	1220	70.2 >128	1.85 >2.11	71	260	3.01	0.48
50	1470	>48.7	1.69	72	940	16.1	1.21
51	0	1.59	0.20	73	960	16.1	1.21
52	1160	20.3	1.31	74	940	14.8	1.17
53	1000	16.7	1.22	75	1000	15.7	1.20
54	530	3.73	0.57	76	1070	22.2	1.35
55	0	1.39	0.14	77	0	1.79	0.25
56	690	10.2	1.01	78	290	3.61	0.56
57	110	7.34	0.87	79	410	4.28	0.63
58	210	>105	>2.02	80	520	5.36	0.73
59	0	1.86	0.27	81	680	7.85	0.90
60	750	11.3	1.05	82	830	11.0	1.04
61	1080	>96.3	>1.98	83	920	14.8	1.17
62	930	>96.1	>1.98	84	960	19.5	1.29
63	0	1.86	0.27	85	1030	29.9	1.48
64	530	6.41	0.81	86	1070	43.7	1.64
65	580	6.86	0.84	87	300	2.89	0.46
66	860	13.5	1.13	88	1120	132	2.12
67	950	18.0	1.26	89	880	13.3	1.12
68	1010	38.8	1.59	90	1170	293	2.47
69	1080	>113	>2.05	...	....	....	....
TESTS 91–101 AT 25 DEG. CENT.							
91	0	0.79	$\bar{1}.90$	97	560	4.32	0.64
92	850	5.81	0.76	98	620	4.60	0.66
93	600	3.06	0.49	99	790	4.82	0.68
94	0	0.87	$\bar{1}.94$	100	860	5.23	0.72
95	270	1.17	0.07	101	960	6.58	0.82
96	360	2.13	0.33	...	...	....	....
TESTS 102–110 AT 100 DEG. CENT.							
102	1450	0.23	$\bar{1}.36$	107	3610	2.33	0.37
103	1780	0.29	$\bar{1}.46$	108	3700	2.58	0.41
104	2350	0.63	$\bar{1}.80$	109	3620	2.48	0.39
105	3060	1.64	0.22	110	640	0.07	$\bar{2}.85$
106	3020	1.36	0.13	...	....	....	....

TABLE 4 VISCOSITY OF TEXACO MEDIUM UNDER PRESSURE

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
TESTS 111–123 AT 25 DEG. CENT.							
111	0	1.26	0.10	118	720	12.0	1.08
112	150	2.13	0.33	119	790	15.0	1.18
113	240	2.71	0.43	120	820	16.2	1.21
114	330	3.94	0.60	121	850	19.4	1.29
115	420	4.93	0.69	122	970	22.8	1.36
116	570	7.04	0.85	...	....	....	....
TEST 124 AT 90 DEG. CENT.							
124	4110	16.5	1.22	...	....	....	....
TESTS 125–140 AT 100 DEG. CENT.							
125	350	0.06	$\bar{2}.78$	133	3050	1.32	0.12
126	1220	0.27	$\bar{1}.43$	134	3300	1.98	0.30
127	1740	0.37	$\bar{1}.57$	135	350	0.06	2.78
128	1880	0.43	$\bar{1}.63$	136	800	0.12	1.08
129	2060	0.50	$\bar{1}.70$	137	1310	0.16	1.20
130	2260	0.56	$\bar{1}.75$	138	1460	0.22	1.34
131	2400	0.65	$\bar{1}.81$	139	1600	0.25	1.40
132	2470	0.77	$\bar{1}.89$	140	1890	0.33	1.52

TABLE 5 VISCOSITY OF MOBILOIL A UNDER PRESSURE

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
TESTS 141–143 AT 20 DEG. CENT.							
141	0	6.06	0.78	143	510	18.6	1.27
142	300	10.3	1.01	...	....	....	....
TESTS 144–162 AT 24 DEG. CENT.							
144	0	2.44	0.39	154	740	46.7	1.67
145	320	6.54	0.82	155	0	3.41	0.53
146	640	13.7	1.14	156	0	3.41	0.53
147	0	3.18	0.50	157	110	5.04	0.70
148	280	8.97	0.95	158	270	8.16	0.91
149	470	19.8	1.30	159	930	111	2.05
150	620	25.1	1.40	160	1120	219	2.34
151	810	59.5	1.78	161	880	93.9	1.97
152	190	6.80	0.83	162	0	3.61	0.56
153	470	21.4	1.33	...	....	....	....
TESTS 163–175 AT 25 DEG. CENT.							
163	0	2.63	0.42	170	1080	93.1	1.97
164	440	13.9	1.14	171	350	10.9	1.04
165	0	2.73	0.44	172	490	16.9	1.23
166	500	14.7	1.17	173	630	24.5	1.39
167	680	25.6	1.41	174	720	36.6	1.56
168	800	42.8	1.63	175	820	49.3	1.69
169	920	58.6	1.77	...	....	....	....
TESTS 176–182 AT 27 DEG. CENT.							
176	0	2.40	0.38	180	810	158	2.20
177	380	9.71	0.99	181	0	2.41	0.38
178	440	12.3	1.09	182	680	16.2	1.21
179	650	45.7	1.66	...	....	....	....
TESTS 183–191 AT 35 DEG. CENT.							
183	350	1.03	0.01	188	1430	31.4	1.50
184	710	3.69	0.43	189	1590	45.1	1.65
185	880	6.87	0.84	190	1750	81.8	1.91
186	1030	10.0	1.00	191	1870	325	2.51
187	1130	14.4	1.16	...	....	....	....
TESTS 192–211 AT 93 DEG. CENT.							
192	350	0.004	(?)	202	1410	0.50	$\bar{1}.10$
193	600	0.04	$\bar{2}.60$	203	1650	0.75	$\bar{1}.88$
194	350	0.04	$\bar{2}.60$	204	1780	0.74	$\bar{1}.87$
195	910	0.22	$\bar{1}.34$	205	1870	1.14	0.06
196	1180	0.32	$\bar{1}.51$	206	1930	1.44	0.16
197	1790	0.84	$\bar{1}.92$	207	2000	1.68	0.23
198	350	0.05	$\bar{2}.70$	208	2030	1.82	0.26
199	650	0.12	$\bar{1}.08$	209	2170	3.98	0.60
200	860	0.18	$\bar{1}.26$	210	2310	6.71	0.83
201	1130	0.33	$\bar{1}.52$	211	2370	9.70	0.99

TABLE 6 VISCOSITY OF CASTOR OIL UNDER PRESSURE (SAMPLE NO. 1)

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
TESTS 212–217 AT 20 DEG. CENT.							
212	0	9.25	0.97	215	1360	>161	>2.21
213	0	7.99	0.90	216	90	9.60	0.98
214	0	9.11	0.96	217	180	12.2	1.09
TESTS 218–229 AT 22 DEG. CENT.							
218	0	7.41	0.87	224	500	35.5	1.55
219	0	7.02	0.85	225	200	8.44	0.93
220	0	8.89	0.95	226	280	9.56	0.98
221	140	12.0	1.08	227	460	10.8	1.03
222	190	12.9	1.11	228	580	12.0	1.08
223	330	15.4	1.19	229	740	26.4	1.42
TESTS 230–240 AT 25 DEG. CENT.							
230	180	7.91	0.90	236	950	18.5	1.27
231	230	7.69	0.89	237	1100	19.5	1.29
232	260	8.50	0.93	238	1280	26.8	1.43
233	420	9.9	1.00	239	1480	44.0	1.64
234	740	13.0	1.11	240	1610	106	>2.03
235	890	17.8	1.25	...	....	....	....
TESTS 319–331 AT 100 DEG. CENT.							
319	350	0.26	$\bar{1}.42$	326	2390	1.40	0.15
320	650	0.30	$\bar{1}.48$	327	2530	1.54	0.19
321	870	0.34	$\bar{1}.53$	328	2670	1.82	0.26
322	1070	0.46	$\bar{1}.66$	329	2760	2.01	0.30
323	1300	0.53	$\bar{1}.72$	330	2970	2.98	0.47
324	1840	0.96	$\bar{1}.98$	331	3060	3.70	0.57
325	2150	1.13	0.05	...	....	....	....

TABLE 7 VISCOSITY OF CASTOR OIL UNDER PRESSURE (SAMPLE NO. 2)

Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ	Test No.	Pressure, p, kg. per sq. cm.	Viscosity, μ, poises	Log μ
			TESTS 241–276 AT 25 DEG. CENT.				
241	0	5.58	0.75	259	540	14.9	1.17
242	0	5.65	0.75	260	680	20.0	1.30
243	0	6.11	0.79	261	970	29.5	1.47
244	40	6.14	0.79	262	1250	41.2	1.62
245	280	8.97	0.94	263	0	6.48	0.81
246	10	6.11	0.79	264	0	5.98	0.78
247	190	7.85	0.90	265	0	6.31	0.80
248	310	8.93	0.95	266	40	6.67	0.82
249	400	9.80	0.99	267	70	7.02	0.85
250	450	10.2	1.01	268	220	9.19	0.96
251	530	11.5	1.06	269	430	12.4	1.09
252	590	12.1	1.08	270	550	16.0	1.20
253	660	13.5	1.13	271	750	21.6	1.33
254	710	14.4	1.16	272	1050	33.2	1.52
255	710	13.9	1.14	273	1280	44.1	1.65
256	0	5.87	0.77	274	1360	51.1	1.71
257	70	7.51	0.88	275	1360	53.0	1.73
258	290	10.3	1.01	276	40	9.83	0.99
			TESTS 277–291 AT 39 DEG. CENT.				
277	0	2.81	0.45	285	2380	52.6	1.72
278	400	5.19	0.72	286	2720	74.3	1.87
279	910	10.4	1.11	287	5520	4.75	0.68
280	1310	16.7	1.22	288	0	2.83	0.45
281	1620	23.7	1.38	289	2700	44.1	1.65
282	1920	33.4	1.52	290	3030	69.8	1.84
283	590	6.73	0.83	291	3300	111	2.05
284	2050	37.2	1.57	...	....	....	....
			TESTS 292–299 AT 60 DEG. CENT.				
292	0	0.70	$\bar{1}.85$	296	1970	6.23	0.80
293	370	1.20	0.08	297	2220	8.21	0.92
294	1070	2.51	0.40	298	2550	11.0	1.04
295	1550	4.00	0.60	299	2920	16.9	1.23
			TESTS 300–304 AT 79 DEG. CENT.				
300	0	0.38	$\underline{1}.58$	303	3360	3.14	0.50
301	1030	0.90	$\bar{1}.96$	304	3910	3.83	0.58
302	3550	3.28	0.52	...	....	....	....
			TESTS 305–318 AT 92 DEG. CENT.				
305	0	0.24	$\underline{1}.38$	312	1880	1.55	$\underline{0}.41$
306	0	0.24	$\bar{1}.38$	313	0	0.24	$\underline{1}.38$
307	390	0.40	$\underline{1}.60$	314	700	0.60	$\bar{1}.78$
308	650	0.49	$\underline{1}.69$	315	1930	1.61	0.21
309	960	0.69	$\underline{1}.84$	316	2300	2.25	0.35
310	1230	0.88	$\bar{1}.95$	317	2630	2.78	$\underline{0}.44$
311	1580	1.21	0.08	318	0	0.24	$\bar{1}.38$
			TESTS 332–335 AT 100 DEG. CENT.				
332	0	0.20	$\underline{1}.30$	334	1680	0.75	$\bar{1}.88$
333	980	0.45	$\bar{1}.65$	335	2290	1.15	0.06
			TESTS 336–350 AT 133 DEG. CENT.				
336	0	0.12	$\bar{1}.08$	344	2380	0.42	$\bar{1}.61$
337	0	0.10	$\underline{1}.00$	345	460	0.15	$\underline{1}.18$
338	230	0.15	$\underline{1}.18$	346	860	0.37	$\underline{1}.57$
339	590	0.19	$\underline{1}.28$	347	1580	0.39	$\bar{1}.59$
340	920	0.22	$\underline{1}.34$	348	2020	1.28	$\underline{0}.11$
341	1380	0.32	$\underline{1}.51$	349	0	0.07	$\underline{2}.85$
342	1680	0.38	$\bar{1}.58$	350	230	0.11	$\bar{1}.04$
343	2050	0.42	$\bar{1}.62$	...	....	....	....
			TESTS 351–357 AT 140 DEG. CENT.				
351	0	0.07	$\underline{2}.85$	355	0	0.09	$\underline{2}.96$
352	380	0.10	$\underline{1}.00$	356	570	0.18	$\bar{1}.26$
353	850	0.28	$\underline{1}.45$	357	640	0.17	$\bar{1}.23$
354	1280	0.40	$\bar{1}.60$	...	....	....	....

GRAPHICAL REPRESENTATION OF RESULTS

Figs. 7–12 represent the essential results obtained.

These diagrams confirm the proposition (see Introduction) that the mineral oils show a greater increase of viscosity than the fixed oils over a moderate range of pressure.

As regards solidification it will be seen that (*a*) lard oil and the paraffin-base mineral oil (Veedol) give pronounced indications of apparent solidification, this effect being more abrupt for the lard oil and more gradual for the paraffin-base oil; (*b*) one of the castor-oil samples (No. 1) offers a faint suggestion of the solidifying tendency, which, if genuine, would be expected to become more pronounced at lower temperatures; while (*c*) the remaining oils showed no indication of solidification.

Determination of the temperature coefficients of viscosity can be facilitated by plotting isopiestics (constant-pressure curves) showing log viscosity against log $(t + 18)$ where t is the temperature in degrees centigrade. These isopiestics are readily obtained from Figs. 7–12 by recording the intersection points of the curves with vertical lines drawn at equally spaced pressure intervals. In this way it was found that the temperature coefficients for all of the oils tested, except lard oil, are considerably greater under high pressure.

Acknowledgment is made to W. H. Herschel of the U. S. Bureau of Standards for assistance in the graphical analysis of results and for helpful criticism during the progress of the investigation.

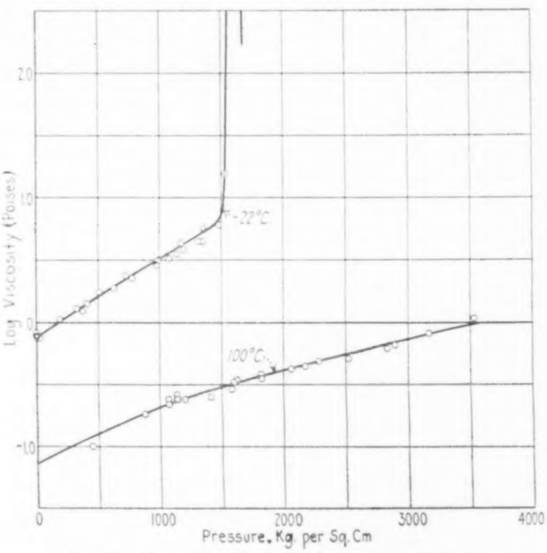

FIG. 7 VISCOSITY OF LARD OIL UNDER PRESSURE

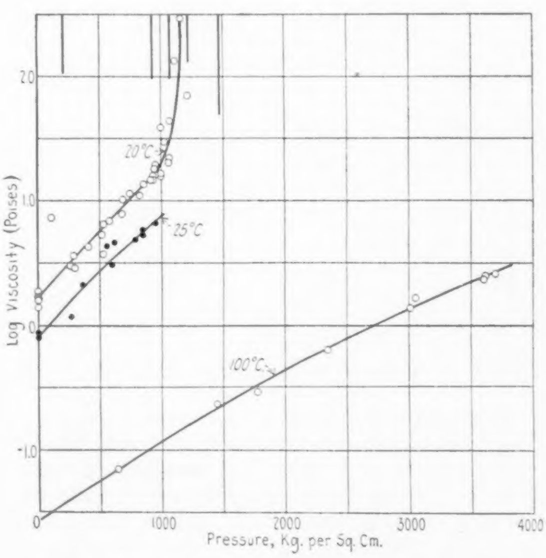

FIG. 8 VISCOSITY OF VEEDOL MEDIUM UNDER PRESSURE

CONCLUSION

Future work in continuation of this problem can be mapped out somewhat as follows:

a Extension to higher pressures and temperatures.

b Critical comparison of existing instruments, including the capillary method of Hyde and the falling-weight method of Bridgman. A start has been made through courtesy of Dr. T. E. Stanton, Superintendent of the Engineering Department of the National Physical Laboratory, in supplying the American Committee with a complete set of the identical oil samples tested by Hyde.

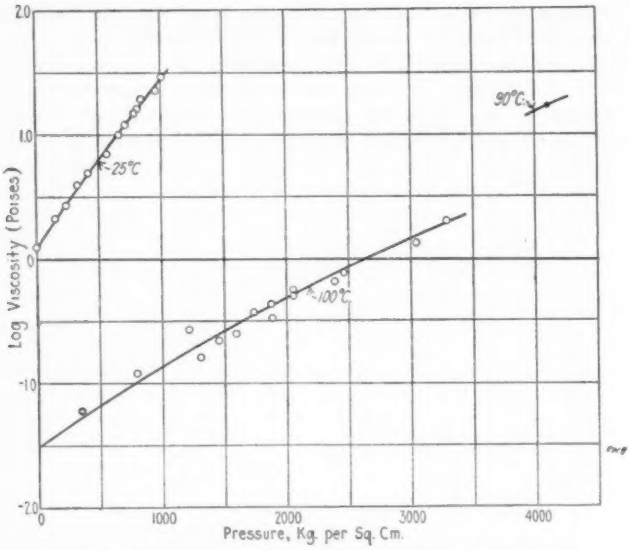

Fig. 9 Viscosity of Texaco Medium Under Pressure

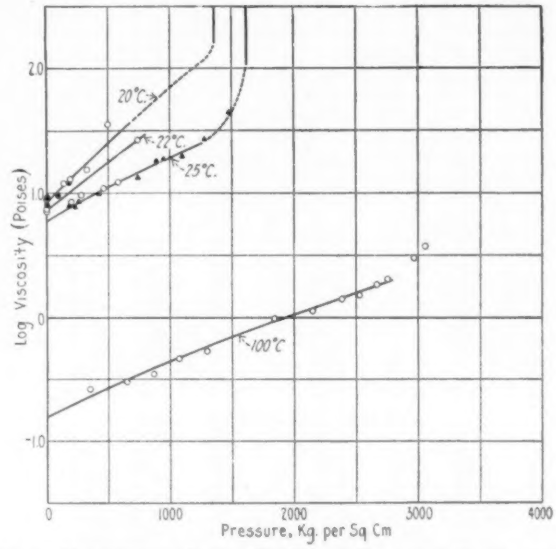

Fig. 11 Viscosity of Castor Oil Under Pressure (Sample No. 1)

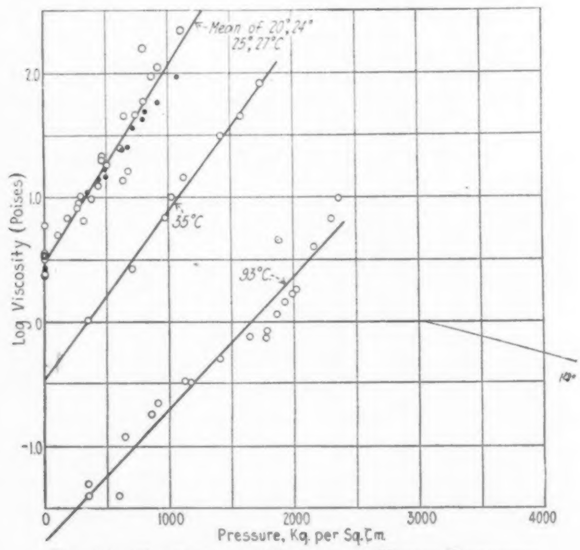

Fig. 10 Viscosity of Mobiloil A Under Pressure

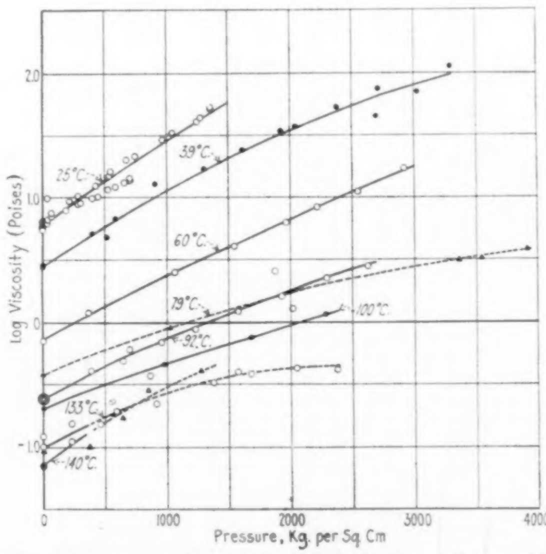

Fig. 12 Viscosity of Castor Oil Under Pressure (Sample No. 2)

c Coordination of data from all sources, in order to arrive at the best representative curves showing the viscosity of lubricants in relation to pressure and temperature. Graphical methods can be used for this purpose over the entire range of the pressure scale, after which the results over a moderate-pressure range should be represented by formulas so that a large number of oils can be compared by tabulating a small number of constants. For practical convenience in making application of the results, pressure values should be given both in kilograms per square centimeter and in pounds per square inch.

d Study of the plastic properties of the oil after apparent solidification sets in, so as to discover the true nature of this effect; and including more precise observations of the transition pressure in order to determine whether the break occurs discontinuously or gradually.

e Viscosity and plasticity measurements on thin films under high pressure, if possible on films that are thin enough to lie within the region of attraction of the surface molecules of the metal.

f Correlation of high-pressure viscosity characteristics with the chemical composition and with the other physical properties of the oil samples, including oleic acid mixtures and compounded oils in the selection of samples to be tested.

g Correlation of the viscosity characteristics of the oils with their frictional performance as determined by quantitative tests on cutting-tool lubrication and by various tests for oiliness in relation to bearing lubrication.

Discussion

D. P. Barnard, 4th.[15] Several years ago the writer conducted a short series of experiments for the purpose of determining whether or not any relation exists between friction and rate of wear under conditions of heavy load and low speed.[16] This work was done with a device consisting of three babbitt-faced

[15] Standard Oil Co. of Indiana, Whiting, Ind.

[16] This work was carried out at the Research Laboratory of Applied Chemistry at the Massachusetts Institute of Technology.

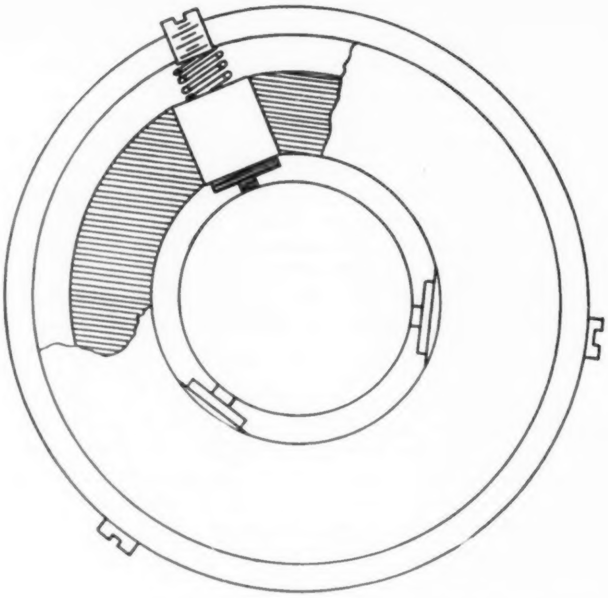

FIG. 13 BABBITT-FACED BLOCKS BEARING ON A HARDENED STEEL JOURNAL

blocks bearing on a hardened steel journal. The experimental conditions were as follows:

Journal diameter	2 in.
Journal length	1 in.
Babbitt-surface length	1/8 in.
Babbitt-surface width	1/2 in.
Test load	1000 lb. per sq. in.
Test speed	16 r.p.m.
Test temperature	75 deg. fahr.

The babbitt surfaces were mounted on hardened steel blocks carefully lapped into the guides of the supporting frame shown in the accompanying Fig. 13. At frequent intervals these blocks were removed and their heights gaged to estimate wear. The blocks were spring-loaded and the frictional resistance was measured by a spring balance. Two complete assemblies were employed, both completely immersed in the same oil reservoir. The two frames should therefore be considered as independent machines operating under identical conditions. The results are given in Fig. 14 and each series shows decreasing wear and friction as the surface of the journal becomes smoother with service. The interesting feature about this work is that while the lard oil gave much lower friction values than the petroleum oil and was characterized by more even operation and much smoother surfaces, the wear was consistently greater than occurred with the latter oil. This observation is contrary to general belief, although several confirming incidents have more recently come to the writer's attention. It is possible that, as the research on viscosity characteristics at high pressures continues, an explanation of this anomalous behavior will be found.

It has been suggested by Dr. W. K. Lewis of M. I. T. that in line with the present theories of the structure of matter, surface adhesion is realized at the expense of cohesion between the surface atoms and those in the interior, and that the stronger the bonds of adhesion, the more are those of cohesion weakened. The lard oil, forming a very tenacious film, when rubbed off would therefore carry more of the surface of the metal with it than would the mineral oil.

The possibility of changing viscosity with rate of shear at high pressure is a feature which may be of much importance. Work at low temperatures carried out at the Engine Laboratory of the Standard Oil Company of Indiana indicates that the various types of oils are characterized by markedly varying behavior under different shear conditions. Some experiments with a Saybolt Universal viscosimeter operated under pressure gave a relation between pressure drop and flow at 0 deg. fahr. which was far from linear, but could generally be expressed by the following equation:

$$\text{Flow} = K \times (\text{Pressure drop})^n$$

for a pressure drop between 1 lb. and 100 lb. per sq. in. It was observed that n varied from 1.1 to 2.5 for oils from different sources at 0 deg. fahr., and in no case was a value of unity obtained for an oil at this temperature. Glycerine gave n = unity for all temperatures at which it was examined. The values of n tend to increase as the temperature is dropped, and vice versa. In some instances $n = 1$ was obtained at temperatures as low as 30 deg. fahr., while in others temperatures as high as 70 deg. fahr. were necessary. While these temperatures are far removed from those normally existing in lubricating films, it still is possible that there may be appreciable effects at the very high rates of shear existing in those films when under considerable static pressure.

WINSLOW H. HERSCHEL.[17] The paper is important in confirming the authors' previous observations of an abrupt apparent

[17] Associate Physicist, Bureau of Standards, Washington, D. C.

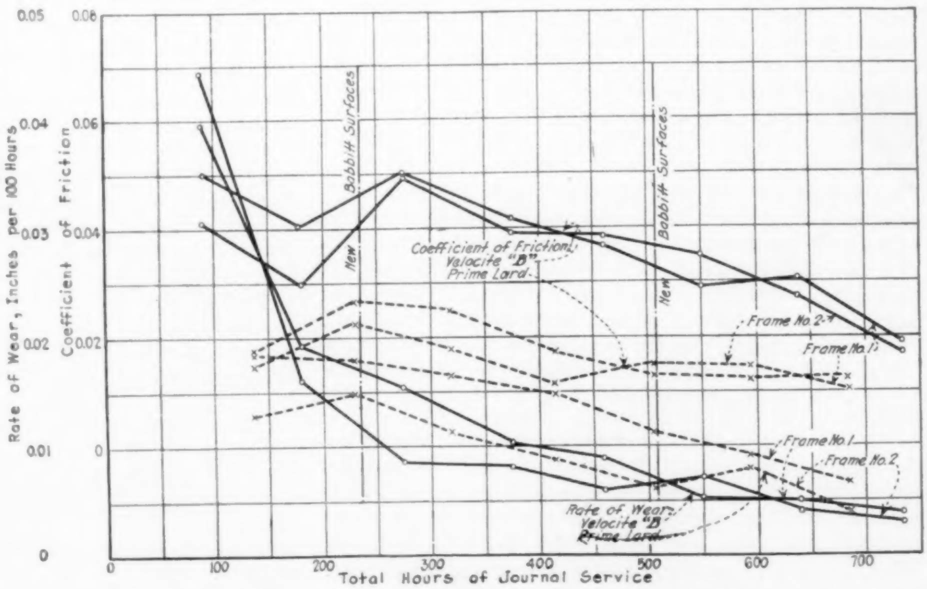

FIG. 14 SHOWING DECREASE IN RATE OF WEAR AND COEFFICIENT OF FRICTION WITH LENGTH OF SERVICE

solidification at high pressures. While the data are not sufficient to indicate the exact nature of this change, it seems probable that there is, at this point, a change from a simple viscous liquid, whose consistency may be expressed by a single numerical value—the absolute viscosity of the oil in poises—to a more complex consistency in which the flow is not proportional to the force producing the flow, and consequently two or more values are required to describe or define the consistency at any one pressure and temperature.

R. V. Kleinschmidt.[18] Mr. Hersey deserves the highest credit for the vigorous manner in which he has pushed forward his work on this very important subject. I feel confident that the subject of change of viscosity with pressure will prove to be not only the explanation of many now obscure phenomena in lubrication, but will furnish the key by which research will soon open up an entirely new field of technique in the compounding and utilization of lubricants.

Some time ago Mr. Hersey arranged for the further development of this subject, utilizing the apparatus which had been developed by Professor Bridgman at the Jefferson Physical laboratory. This apparatus, which would extend the range of pressures to 12,000 atmospheres, was already developed to a high state of perfection, and promised an ideal opportunity to do a large amount of valuable work at the very minimum expense. Professor Kingsbury generously offered to guarantee the funds for two months' work, and during this time enough work was accomplished to verify the results of the paper just presented and to extend the results to the higher range of pressures. While the work was in progress strenuous but unsuccessful efforts were made to raise further funds for the work. Neither the machine-tool manufacturers nor the oil companies saw the value of the work concretely enough to advance even a few hundred dollars, and the work stopped just as it was well started. Here was a rare opportunity to utilize free of charge apparatus which could probably not be duplicated for several thousand dollars, the result of years of experience in the field of high-pressure technique, and the lack of a thousand dollars made it necessary to pass it by.

There are two morals that may be drawn from this brief story. The first is that you must back the men who are trained for research with money, or their efforts are practically wasted. The second moral is perhaps less obvious but more specific. Research presents a bewildering array of possible fields of exploration. There is a constant tendency to dabble a little in each field, to spend a few pennies here and a few there in order to appear impartial to any one branch of our membership. The futility and wastefulness of such a policy is perhaps emphasized by the history of these experiments.

The work of research is at best attended with an element of uncertainty which in certain fields is perilously close to danger. The research worker who is hampered by lack of funds is forced to use makeshift apparatus which is often operated close to the failure point. Therefore in the interests of safety, if for no other reason, adequate funds must be considered essential for research.

I cannot help feeling that the results indicated by Mr. Hersey are of such interest that they should be made the basis for a complete and thorough study of the subject.

A. E. Flowers.[19] The author gives an exceedingly complete and very good description of the methods which he has used for obtaining definite measurements of viscosity at unusually high pressures. Fortunately it has been carried up into a range well beyond probable bearing pressures and into the range where cutting tools may be operated. The only thing that the writer can see that might possibly affect in any way the corrections that have already been applied by Mr. Hersey in calculating results, is the question of the effect of the possible change in ratio of ball diameter to tube diameter due to the internal pressure in the viscosity tube, which may be expected to stretch the walls of the tube slightly and to somewhat compress the ball. In some earlier work of the writer's on that question he found that for certain ratios of ball diameter to tube diameter the effect of a small change in that ratio was quite well marked. For ratios of ball to tube diameter greater than something over 0.5, perhaps of the order of 0.75, the change of roll time due to a change in ratio of dimensions can be quite well marked.

Closure to Discussion

M. D. Hersey. The diagram offered by Mr. Barnard shows quantitatively what has already been recognized qualitatively, that the oil giving the less friction may give the greater wear; and, as he suggests, it will be of interest to discover what correlation exists between the wear observed with a series of oils, and their change of viscosity under pressure.

The authors are in full agreement with the comments offered by Mr. Barnard and by Mr. Herschel regarding the plastic nature of the lubricant under extremely high pressures.

In response to Dr. Kleinschmidt's remarks, it can be stated that the continuation of this research, as well as other closely related problems, has been definitely authorized by the Director of the Bureau of Standards within a few months past. Nothing is lacking except funds.

As suggested by Dr. Flowers, a correction might be thought necessary for the reduction of roll time due to the increase of tube diameter and decrease of ball diameter under high pressure. Anticipating this question, experiments had been made with glass tubes of two different diameters, using balls of two different diameters, and from these experiments it was found that the percentage decrease of roll time was approximately five times the corresponding increase of tube diameter and about twice the corresponding decrease of ball diameter. These data combined with simple calculations from the theory of elasticity proved that the necessary correction could not exceed one-half of one per cent at the highest pressures used.

Mr. A. L. Davis[20] referred to the unexplained results obtained with different lubricants in roll-neck lubrication, where the pressures and temperatures are undoubtedly very high. The present investigation is intended as a step toward the solution of just such questions as that.

As the experiments reported in this paper have been conducted entirely in spare time, they have necessarily extended over a long period, and in the meanwhile other investigators have attacked the same problem. Besides the work of Hyde at the National Physical Laboratory, reference should be made to Dr. Kleinschmidt's experiments, described in Appendix 1 of the Committee Report (1927) entitled "Progress in Lubrication Research," and to two papers by Dr. Ing. S. Kiesskalt at the Karlsruhe Technischen Hochschule. Dr. Kiesskalt's first paper, "Untersuchungen über den Einfluss des Druckes auf die Zähigkeit von Oelen," etc.,[21] contains experimental results together with empirical equations. His second paper, "Bedeutung der ydrodynamischen Lagerreibungstheorie für die Praxis,"[22] undertakes to modify the hydrodynamic theory so as to allow for variations in viscosity due to pressure and temperature.

[18] Physicist and Research Engineer, Arthur D. Little, Inc., Cambridge, Mass. Jun. A.S.M.E.

[19] Engineer in Charge of Development, De Laval Separator Co., Poughkeepsie, N. Y. Mem. A.S.M.E.

[20] Research Engineer, Scoville Mfg. Co., Waterbury, Conn. Mem. A.S.M.E.

[21] *Forschungsarbeiten aus den Gebiete des Ingenieurwesens*, Heft, 291, 1927.

[22] *Zeit. V. d. Ing.*, vol. 71, p. 218, 1927.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

CORROSION

An Investigation of the Corrosion of Metals with a Thermobalance

IN INVESTIGATING the corrosion of metals the usual method consists either in macroscopic or microscopic observation of the metal surface, or in suspending the specimen in a certain corroding solution for a given interval of time, the corrosion products being then removed and the corrosion loss determined by means of an ordinary balance. There has as yet been no attempt made to follow attentively and without interruption the change in weight of the metal during the progress of the corrosion. In the present work the thermobalance which was originally devised by Dr. K. Honda was used for the continuous observation mentioned above. It is well known that this thermobalance has been used very effectively in observing the change in weight accompanying chemical changes. The article under consideration here contains the results obtained in the present investigation which was carried out under the direction of Professor Honda.

For this purpose a kind of thermobalance was made from an ordinary chemical balance. The specimen was a commercial iron sheet and the corroding solutions consisted of the following seven reagents of various concentrations: water, sodium chloride, sodium carbonate, sodium bicarbonate, sodium nitrate, sodium sulphate, and potassium hydroxide, the experiments being carried out at 45 deg. cent.

Generally, in these solutions the iron corrodes with the formation of flocculent and easily detachable ferric bicarbonate solutions; in this case a gelatinous corrosion product was formed on the metal surface and could not be detached easily, and the weight of the sample was increased continuously. Owing to the formation of hydrogen-gas bubbles on the metal surface, continuous measurement could not be carried out in acid solutions. (Kenzo Inamura in *Science Reports of the Tohoku Imperial University*, Sendai, Japan, 1st Series, vol. 16, no. 8, Dec., 1927, pp. 987–997, 8 figs., *e*)

The Action of Water, Air, Oxygen, and Carbon Dioxide in the Corrosion of Iron

THE article gives a brief survey with references to previous work and proceeds to describe experiments. In the tests carried out with Armco iron the action of distilled water, city water, and sodium chloride solution was first studied and it was found that if there is no supply of air the water appears to have no appreciable action upon the iron. Next, the sample was kept in a glass flask containing pure water and the action of air, oxygen, and carbon dioxide was studied. It was shown that the action of carbon dioxide is weaker than that of oxygen when both are alone; on the other hand, carbon dioxide accelerates the rate of corrosion by oxygen, though not to a very great extent. It would appear from the foregoing, therefore, that a supply of oxygen is necessary for corrosion. The accelerating effect of carbon dioxide on the rate of corrosion by oxygen was found to be smaller than is usually believed to be the case. (Kenzo Inamura in *Science Reports of the Tohoku Imperial University*, Sendai, Japan, 1st Series, vol. 16, no. 8, Dec., 1927, pp. 979–986, 1 fig., *e*)

ENGINEERING MATERIALS (See Machine Shop and Metallurgy)

FOUNDRY (See Metallurgy: Aluminum and Aluminum Cast Irons)

FUELS AND FIRING

Total Distillation of Coal on the Stein-Tully System at Versailles

THE Stein-Tully system of coal distillation comprises the following essential parts: First comes a gas generator consisting of a sheet-steel cylinder closed at the ends and lined inside with firebrick. Its upper part consists of a head covered by refractory lining, and it is there that the distillation of coal takes place. The lower part collects the coke as it is formed and may be compared to a water-gas generator. It is provided with a grate and ports for ash removal. The charging hopper is located on top of the apparatus. The next essential element is the power-driven ventilator providing air under pressure for the reheating of the coke after each period of gasification and for burning the carbon monoxide carried away by the blower gases. A gas washer comes next. This is a steel-plate container with two pipes. Its purpose is to provide the first stage of condensation of the condensable products and the first stage of dust removal. It also acts as a hydraulic seal. The next stages of condensation and dust removal take place in a scrubber washer, a column of coke of the usual type. The gas obtained is a mixture of the gas produced by the distillation and water gas. Its production cannot be made continuous, since the reaction making the water gas is endothermic (which means that it absorbs heat at the expense of the incandescent mass of coke). It is therefore necessary after a certain time to stop the injection of steam and wait until the coke bed is brought to incandescence. For practical purposes the temperature of the coke should not be permitted to go below approximately 600 deg. cent., as below this temperature steam is not dissociated.

The production of the "total" gas takes place in a series of cycles, each of which comprises a period of air injection or reheating of the coal and a period of steam injection or gasification proper. The duration of each of these periods, while not exceeding a few minutes, may be quite variable, and is a function of the velocity, and hence pressure of the current of air delivered under the producer grate by the blower, of the pressure of the injected steam, etc. As an average it may be said that the period of air blowing is about 2 min. and the period of steam injection from 8 to 10 min. After a certain number of cycles coal is added to the producer, and every few hours the apparatus is stopped and cleaned. The original article gives the details of the manufacture and construction. The installation at Versailles has two producers of 5000 cu. m. capacity (176,500 cu. ft.) each 24 hr., which means an output of 10,000 cu. m. (353,000 cu. ft.) of the Stein-Tully gas, and 20,000 cu. m. (706,000 cu. ft.) of distillation gas from the furnaces. [The article does not explain exactly what this latter type of gas means.—Editor.] (Charles Dantin in *Le Genie Civil*, vol. 91, no. 19, Nov. 5, 1927, pp. 453–457, 9 figs., *d*)

INTERNAL-COMBUSTION ENGINEERING

The A.E.G. New Type of Solid-Injection Double-Acting Two-Stroke Oil Engine

THE A.E.G. is one of the largest manufacturing companies in Germany. While primarily an electric company, it is also making various other engineering products, among them internal-combustion engines. In this field it operates under a patent arrangement with Burmeister & Wain, of Copenhagen, and also controls for Germany the patents of the Swedish engineer K. J. E. Hesselman (MECHANICAL ENGINEERING, vol. 44, no. 8, Aug., 1922, p. 531). It appears now to have developed a new type of its own.

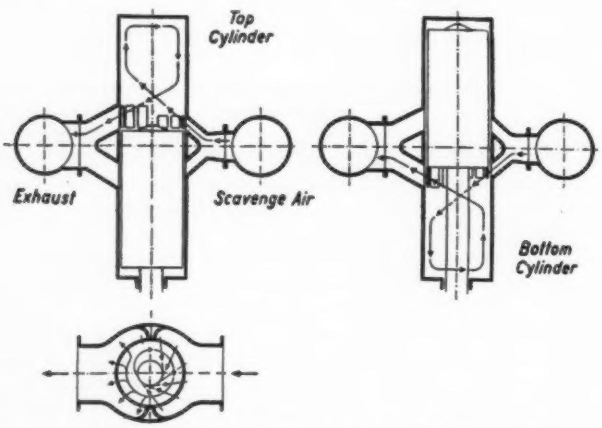

FIG. 1 PRINCIPLE OF SCAVENGING OF A.E.G.-HESSELMAN ENGINE

The first experimental cylinder with a diameter of $26^3/_4$ in. and a stroke of $47^1/_4$ in. was built in the spring of 1926. It is claimed to have developed close to 1000 b.hp. at 120 r.p.m. and to be quite successful.

Some features of the test are interesting. To determine the degree of scavenging, of particular importance in an airless-injection engine, and also the degree to which fuel and air are evenly mixed, a glass cylinder having the same dimensions as the test engine was built. The cover and bottom of this glass cylinder were made of wood and fitted with openings to introduce a pitot tube for measuring the air velocities in the glass cylinder. The profile of cover and bottom corresponded to the shape of the combustion chamber. The lower part, also consisting of wood, contained the scavenging ports and the exhaust ports. This part was interchangeable with the view of examining as many different arrangements of ports as possible. A steel pipe fixed in the axis of the glass cylinder carried a number of radially directed wires from which varicolored woolen threads were suspended indicating the direction of the air flow. The scavenge air was supplied by an electrically driven turbo-blower built for an air volume of 85,000 cu. ft. per min. at a back pressure of 0.85 lb. per sq. in. This air volume just sufficed to permanently maintain an air pressure of 0.6 lb. per sq. in. in the glass cylinder under constant flow. This allowed a perfect control of the different diagrams of flow resulting from an alteration of the scavenge and exhaust ports. While the constant air flow does not correspond to the actual conditions in the Diesel cylinder in which the constantly moving piston releases the scavenge and exhaust ports for fractions of a second only, there is scarcely any other means to trace the scavenge procedure than through the stationary flow. Indeed, the time during which the process takes place in the engine is too short for observation with the naked eye, and the air flow cannot be made sufficiently visible to obtain a photograph. But valuable information can be got by studying the stationary flow of the scavenge air through the cylinder, thus allowing one to judge the efficacy of scavenging to be expected beforehand.

In all, thirty-three different arrangements of scavenge and exhaust ports were tested. In these experiments not only the number of ports, but also their tangential and axial directions were varied. The course of the scavenge air could be distinctly demonstrated by introducing burning rockets into the scavenge ports, or through openings in the cylinder cover. During a considerable length of time the track of the glowing sparks could be clearly followed, and a photo was taken of each single test. The more the scavenge ports were inclined in a tangential direction, the higher was the peripheral velocity of the air. But simultaneously the air particles always moved in more horizontal tracks, though the axial inclination of the scavenge ports remained unchanged. When the scavenge ports were too much inclined in the direction of the tangent, the air at last moved in nothing but quite flat spirals about the cylinder axis. In this case the cylinder would not be scavenged effectively on account of the air ascending too slowly from the scavenge ports to the cylinder cover, and in the short time during which the scavenge ports are open, the exhaust gases cannot be perfectly eliminated from the cylinder. Similar observations could be very well made with sawdust blown in at various points into the scavenge ports. When regularly scavenged the sawdust rose in a steep spiral line from the scavenge ports towards the cylinder cover. Then it returned and moved downward again, afterward disappearing immediately through the exhaust ports. In the case of insufficient scavenging, however, the sawdust circulated permanently in the cylinder, leaving the latter only after a comparatively long time through the exhaust ports.

The adoption of a scavenge system as demonstrated in Fig. 1 was the result of the tests continued during several months. From the intake manifold placed on one side of the cylinder the scavenge air enters the cylinder through ports axially and

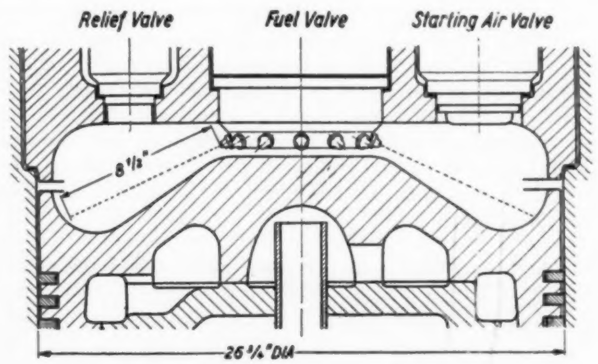

FIG. 2 TOP COMBUSTION CHAMBER, NEW DESIGN

tangentially arranged at given angles. In the cylinder it performs with a certain angular velocity a helical movement, issuing after a rotation of about 540 deg. through the exhaust ports placed on the opposite side. The helical movement of the air continues, even although, during the upstroke, the piston has covered the scavenge and exhaust ports. As the piston rises, the air only takes an increasingly flatter course until it rotates practically in a plane. The angular velocity of the air is such as to be just intense enough to describe, during the time of a fuel injection, an angle equal to the angle between two adjacent fuel sprays. In this case each fuel particle comes once, and only once, into contact with the air. The air and fuel mixture is as perfect as possible, thus warranting an exceptionally good combustion.

As regards the combustion chamber, tests have shown that in

the original Hesselman engine, even with high pump pressures, the penetration of the fuel sprays is only a very limited one. Consequently it was decided to shorten the length of the fuel sprays and this is done in the chamber shown in Fig. 2, where the central part of the piston is flat and a row of nozzles, each with one hole on the circle round the cylinder axis, is arranged

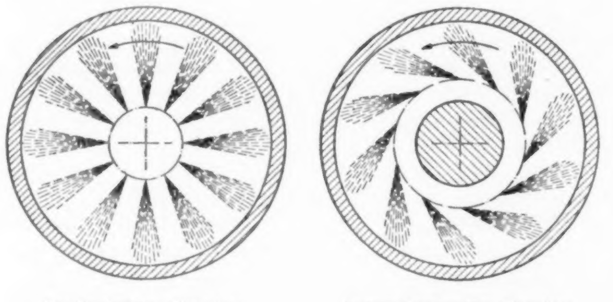

FIG. 3 NEW ARRANGEMENTS OF FUEL SPRAYS

instead of a single one having several holes. For the same cylinder diameter as formerly ($26^3/_4$ in.) and an identical volume of the compression chamber, the necessary length of the fuel sprays is reduced to $8^1/_2$ in. only. As shown by the photographic tests, such length can be reached under a suitable pump pressure (of about 4500 to 5000 lb. per sq. in.). By the adoption of this form of combustion chamber the air at the outer periphery is reached by the fuel sprays, and the mixture of fuel and air is therefore particularly good.

On the bottom side of a double-acting oil engine where formerly it was extremely difficult to obtain a sufficient mixture of fuel and air, the difficulty in part was overcome by Hesselman's system of arranging several fuel valves on a circle around the piston rod, each fuel valve developing two fuel sprays. A slightly inclined position is now given to the fuel valves, which (1) permits the nozzles to be brought as near to the piston rod as possible, and (2) provides the required space for the piston-rod gland. With the cylinder diameter of $26^3/_4$ in. the sprays are only $6^1/_2$ in. long, provided the penetration of the fuel sprays is less on the bottom side than on the top side. The mixture of fuel and air, however, due to the short length of sprays is not as uniform as on the top side. This is helped in part by inclining the fuel sprays on the bottom side in the sense of the air rotation as shown in Fig. 3.

The fuel valves are essentially the Hesselman design with his membrane disks. This cannot be described here on account of lack of space. The fuel pump is of the normal type for airless injection, excepting that it is designed for a fuel pressure of 4000 to 5000 lb. per sq. in. and that all air traps are absolutely avoided.

In the test results it was found that at full load (1000 b.hp. at 120 r.p.m.) the mean effective pressure is 65 lb. per sq. in., which is rather low for a cylinder of the given size. This corresponds to a mechanical efficiency of the engine of about 88 per cent. The fuel consumption is 0.353 lb. per b.hp-hr. In the test results the power required for the scavenge-air turbo-blower designed for an output of about 5000 cu. ft. of air per min. has been taken into account.

The advantage of an engine of this type is said to be not in its high mechanical or thermal efficiency but in its simplicity, warranting high reliability. It is claimed that because of the absence of mechanically operated valves, valve rods, camshafts, etc. it assumes a very simple appearance, while its reduced overall length and small weight per shaft horsepower (162 lb. in a six-cylinder design) are of advantage for marine purposes. (Dr. F. Sass, in *Transactions of the Institute of Marine Engineers*, vol. 39, Dec., 1927, original article, pp. 627–669, 36 figs., and discussion, pp. 669–689, *dA*)

Standards of Thermal Efficiency for Internal-Combustion Motors

THE Heat Engine Trials Committee, in their recent report, after recording their acceptance of the 1905 Air Standard, proceed to discuss the ideal efficiency standards for four distinct engine cycles: (1) constant-volume; (2) constant-pressure; (3) Diesel; and (4) Atkinson. Air is still used for the working fluid, but it is real air, with specific heat varying with temperature, not the ideal air with constant specific heat as used by the Institution committee of 1905. The specific-heat values adopted are those published by Partington and Shilling, ranging from 100 deg. cent. to 2000 deg. cent., and constant-volume values from 19.7 ft-lb. per standard cubic foot to 25.9 ft-lb. at the highest temperature. The corresponding γ values are 1.399 and 1.303. The thermal efficiencies η, following those assumptions, are obtained by means of the well-known equation:

$$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

but instead of $\gamma - 1 = 0.4$ as in the old air standard, the exponent becomes 0.399 for 100 deg. cent., and 0.303 for 2000 deg. cent. The exponent selected for the efficiency calculations varies with the temperature due to the heat input, and it is obtained from equations which vary for the different heat contents. In the case of the constant-volume and constant-pressure cycles, the equation is:

$$n = 0.404 - 0.0012\, I$$

where I is the heat-input in centigrade-pound heat units per standard cubic foot.

For the constant-pressure engine, the Heat-Engine Trials Committee have adopted the γ value of 1.382, and the corresponding volumetric heat $\bar{C}_v = 20.5$ for a heat input of $I = 30$ C.H.U., and $\gamma = 1.364$ and $\bar{C}_v = 23.5$ for $I = 60$ C.H.U. Those values are quite justifiable for the temperature change between constant-volume and constant-pressure engines. From the values, the Committee have prepared four useful tables giving ideal thermal-efficiency values for compression-ratios ranging from 4 to 20, and heat inputs from 5 to 60 C.H.U. Comparisons are also made between relative efficiencies and those of the old air standard. The efficiency values given by the Committee are in all cases lower. In the cases of the Diesel and Atkinson cycles, the report deals with the $\gamma - 1$ values as in the two cycles just discussed. The attempt is made to find values for the exponent n which will similarly express the efficiency variation. In this matter the author differs from his colleagues, the proceeding, in his view, being erroneous both in principle and practice. It is erroneous to use Equation [1] for the Diesel diagram by trimming the exponent to obtain the changing η value by means of an impossible value. The correct procedure is to find the mean temperature of expansion on the assumption of no heat loss and take out the volumetric heat at constant volume from a table, then use that value to get the corresponding γ. This $\gamma - 1$ gives the true exponent for the assumed expanding air.

It is quite legitimate to use the varying exponent in Equation [1] for the three symmetrical cycles, because the same equation is common to the three. When Equations [2] and [3] deal with

the modified cycles, the Diesel and Atkinson cycles, it is necessary to use the real $\overline{C}_v$ values so far as they can be ascertained.

$$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1} \times \frac{\rho^{\gamma} - 1}{(\rho - 1)\gamma} \qquad [2]$$

$$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1} \times \frac{(\rho - 1)\gamma}{\rho^{\gamma} - 1} \qquad [3]$$

In Equation [2], ρ is the ratio of the volume behind the piston at the point of cut-off of the heat supply to the volume of compression. In Equation [3], ρ is the ratio of the volume at atmospheric pressure after expansion to the total volume behind the piston before compression.

Calculating from a formula given by the Committee for the exponent n to be used in the Diesel cycle, n ranges from 0.290 to 0.240 for a range of heat input of 30 to 50. The exponent n for the Atkinson cycle, calculated in the same way, ranges between 0.498 and 0.517 for heat inputs from 30 to 60. The exponent for the Diesel cycle, if assumed to by $\gamma - 1$, gives very high volumetric heat equivalents, 26.7 to 32.3 ft-lb., respectively, per standard cubic foot. The Atkinson exponent values are all high and the corresponding specific heat is low. For the value of the exponent 0.517, the volumetric heat is only 15 ft-lb. per standard cubic foot, which is less than one-half of the value in the case of the Diesel cycle at exponent value 0.240. The method leads to the use of false specific heats.

No doubt the Committee recognize the artificial nature of the exponent n as used in the Diesel and Atkinson cycles, and do not intend to value specific heats of gases in the manner shown above.

The air standard, Equation [1], gives higher ideal thermal-efficiency values than could be obtained by the actual working fluid of the engines, because the volumetric heats of products of combustion are higher than that of the assumed air. It is accordingly important to obtain the true values in order to find the extent of possible improvement in the actual engine. If the actual working fluid had the same properties as the ideal air, then, at 70 per cent relative efficiency, 30 per cent of the total heat still remains to be utilized to produce motive power if all heat losses are avoided. It is for this purpose that true $\overline{C}_v$ and γ values are required, and determinations were made by the author in 1905 and 1906 by the then new method of compression and expansion of the flame gases in the cylinder of a gas engine of 14 in. bore and 22 in. stroke. The apparent specific heats were so determined up to 1500 deg. cent. The mean $\overline{C}_v$ value of the actual working fluid in the case of that particular engine was 27.2 ft-lb. per standard cubic foot, and the corresponding $\gamma = 1.285$ and ideal thermal efficiency $\eta = 0.381$. The actual indicated thermal efficiency was 0.338, so that the relative efficiency was 0.89. That is, the real working fluid under conditions of no heat losses could give 38.1 per cent thermal efficiency, and the actual results with the heat losses of the engine was 33.8 per cent, or 89 per cent of the possible ideal value. In the true case there only remained 11 per cent on which to make further savings instead of $30^1/_2$ per cent, as indicated by the air standard.

The knowledge now in existence permits of the adoption of the properties of the actual working fluid for such investigations. The $\overline{C}_v$ and γ values could be prepared from Partington and Shilling's table for air, carbon dioxide, and steam, and more accurate comparisons between real and ideal could then be made for all engines using gaseous fuel. For gasoline engines, the valuable work of Ricardo, and of Messrs. Tizard and Pye, gives reliable ratios, including allowances for dissociation at high temperatures and for the volume expansion due to molecular change.

It is thought that the time has come for the application of accumulated knowledge to the substitution of real working fluids for the ideal properties, which were necessary because of ignorance of the real.

The Atkinson cycle, as a standard for all types of engine, is a suitable ideal cycle for comparison with a similarly operating cycle in actual use, but for no other. For constant-volume engines, the relative efficiencies would be very much too low. It would increase the error of the old air cycle in constant-volume engines by showing an impossible margin still remaining for themselves for thermodynamic improvement. The relative efficiencies given, compared with the Atkinson cycle, as calculated in the report are for

Gasoline engines	53.1 per cent
Gas engines	59.1 per cent
Airless-injection oil engines	59.5 per cent

That is, all these engines, according to this method of calculation, seem to have a possibility of utilizing to better advantage, respectively, 46.9, 40.9, and 40.5 per cent of the heat given to them. No such possibility exists, as the consideration of the actual properties of the working fluid accounts, at present, for nearly 90 per cent of the total heat which they could possibly turn into work. (From a paper read Jan. 10, 1928, before the Institution of Civil Engineers by Sir Dugald Clerk; abstracted from preprint in *Engineering*, vol. 125, no. 3234, Jan. 6, 1928, p. 10, *tA*)

MACHINE PARTS AND DESIGN

Air-Hardening Rivet Steels

A STUDY was made at the request of the Bureau of Ordnance, War Department, of a series of alloy steels possessing air-hardening qualities for the purpose of determining their applicability for rivets which would have a ballistic resistance at least approaching that of the armor plate which they joined.

The steels selected for this study included for the most part those of the chromium-nickel series and some containing additions of manganese and molybdenum. In addition to the variation of alloy content, the carbon content was also varied, which permitted a study of the effect of each of these factors.

These steels were tested in the finished rivet forms as well as in other ways—as, for example, the tensile test. The results pointed to the shear test as the best single indicator of the true value of any particular steel for rivet use. From this test a fair prediction, at least, could be made of the ballistic and impact properties of the various steels used.

The following are some of the principal conclusions drawn by the author of the paper:

Air-hardening steels within certain limits are very satisfactory for rivets. With such steels riveted joints were produced under ordinary shop conditions which were four to five times as strong as those made with ordinary carbon-steel rivets, and more than twice as strong as those made with best (non-air-hardening) nickel rivet steels.

The regulation of the carbon in an alloy steel is very important, there being an optimum carbon content for each particular type of alloy steel. For a steel containing 3.5 per cent nickel and 1.5 per cent chromium the optimum carbon is very close to 0.20 per cent.

A drawback in the use of air-hardening steels for rivets is the loosening of "long-shanked" rivets as a result of expansion caused by the change of austenite to martensite (Ar'') which takes place at relatively low temperatures. This difficulty, however, was not met in rivets of the lengths used in tanks, and it is believed that sufficient lowering of the carbon will avoid

this trouble even in longer rivets. This may cause a decrease in strength, but this loss would tend to be counterbalanced by an increased toughness.

Rivets which showed good mechanical properties and had Rockwell hardness ("C" scale) in the range of 40 to 50 showed excellent ballistic properties. The ballistic properties are a good measure of the impact resistance of a material. Hence steels of the chromium-nickel series containing 0.17 to 0.25 per cent carbon should show high impact resistance, the maximum probably being reached by an 0.20 per cent carbon content.

The steels tested are listed according to cost of the total alloy content. The steels containing molybdenum were not as tough as the best of the nickel-chromium steels. However, improved toughness in the molybdenum steels can doubtless readily be obtained without too great a sacrifice of strength by a reduction of the carbon content.

The paper gives tables showing the physical properties of various materials which are of general interest. (Harry K. Herschmann in *Technologic Papers of the Bureau of Standards*, vol. 22, no. 358, Oct. 19, 1927, pp. 141-169, 19 figs., *eA*)

MACHINE SHOP

Machinability of Metals

THE object of this paper is to outline the various methods which are being used to designate the machinability of metals and to present substantiating data. The work of many authors has been referred to and their conclusions on certain phases of machinability have been presented. This work involves different methods and standards, which in many instances makes comparisons difficult. Ways for designating the relative machinability of various metals have been presented. Because of the large field covered, it is impracticable to summarize and state the conclusions. Some methods show consistent relations between the factor of machinability and the physical properties of the materials which offer general guidance in practical work.

It would be well if the various methods of testing machinability could be compared by direct data from the test bars so as to find if the torque or the feed in inches per 100 revolutions of the drill; or the force, power, tool endurance, or Taylor speed, etc. in straight cutting or turning; the energy absorbed by a milling cutter, etc. have anything in common.

Further, for determining the machinability of a metal under variable conditions, it appears that continued study of the properties of the metals at elevated temperatures as caused by the heat generated in cutting, the work hardening by the tool of the material being cut, as well as further light on the subject of chip formation, will lead directly to a more thorough understanding of the principles underlying metal cutting.

Several methods are described in detail as having been used to determine the relative machinability of metals. In each case the author gives references to previous investigations and at times his own criticisms. The methods referred to are as follows:

The measurement of the force in the direction of the cut on a tool of given geometric form required to remove a chip of definite cross-sectional area and shape at a given speed.

The measurement of the power required for a standardized tool to remove a specific chip of various materials.

The ability of a standardized tool to cut various materials. This may be measured (*a*) in terms of the life of the tool for a given cutting speed, or (*b*) in terms of the cutting speed for a definite tool life.

A measurement of the finish left on the cut surface for various metals under standardized conditions.

The penetration of a standardized drill rotating at definite speed and under uniform load when cutting various metals.

The torque developed by a drill while drilling various metals under standardized conditions.

A cutting speed for certain tool life expressed in terms of tensile strength, reduction of area, or percentage of elongation of the various materials.

The hardness numbers of the materials as indicated by a hardness-testing machine.

The measurement of heat generated and hardness induced by the cutting process. [Orlan W. Boston (Mem. A.S.M.E.), Professor of Shop Practice, University of Michigan, Ann Arbor, Mich., in *Transactions of the American Society for Steel Treating*, vol. 31, no. 1, Jan., 1928, pp. 49-86, bibliography, pp. 84-86, *gA*]

Building Large Steam-Turbine Spindles

THE PROBLEM of turbine-spindle design has materially increased in difficulty with the size of turbines. Not so long ago a 10,000-kw. turbine was considered large. Today units of 250,000 kw. are being considered, and a few years from now who knows but that half a million kilowatts may be generated under the control of one governor? In the increase in capacity of units and the consequent lengthening of blades, the centrifugal stresses were much increased. The early spindles were of drum-type construction with blade rings pressed on one end of the drum and dummy rings pressed on the other. This was satisfactory with turbine capacities up to about 7500 kw. With increase in size of turbine units and the consequent lengthening of blades, solid spindles made of plain normalized carbon steel were adopted. Still later, with further increase in size of turbines, it became necessary to provide an individual disk for each of the last few rows of blades on the spindle. Today forged disks of nickel steel can be obtained, having physical properties suitable for an average stress of 26,000 lb. per sq. in. or a maximum at the center hole of 55,000 lb. per sq. in. In the actual process of designing a spindle the first step is the determination of the blading, i.e., proportioning the diameters of the rotor and the blade lengths to give the desired area for economical passage of the steam. The next step is to determine how best to distribute the metal to support the blades. The upper limit of peripheral speed is 110 ft. per sec. in the bearings with a few exceptions, while the pressure per square inch of projected area is seldom permitted to go beyond 175 lb.

The critical speed should always be at least 30 per cent above the running speed. In addition to the calculation of critical speed a complete analysis is made of the stresses in the various parts of the spindle arising from the force of rotation plus the blade load. The average stress when using normalized carbon-steel forgings should not exceed 20,000 lb. per sq. in. at 20 per cent overspeed, while the maximum local stress should not exceed 40,000 lb. per sq. in. In large units where the total mass would be too great to permit manufacture in one piece, two main forgings are employed, bolted together. The bolting of these two sections of a spindle together so that they will remain fixed in relation to each other is a problem needing special care. The usual way is to make the joint with a tapered press fit, with the more highly stressed piece on the inside. Bolts of special construction are used for this purpose (details in the original article).

The manufacture of the forgings for big spindles is a job requiring, great care and experience. The original article shows the forging for the coupling-end half of a spindle. When rough-machined it weighs 84,400 lb. but is produced from an 82-in. octagonal ingot which weighed 208,000 lb. and was made from two open hearth furnaces. The body of the ingot weighs 165,000 lb. and 43,000 lb. are on the hot top. After solidification, without becoming cold, the ingot is brought to a forging heat, and rounded up to approximately 70 in. diameter and 142 in. long. Approximately 23 in. of this length is drawn down to a shank 36 in. in

diameter by 45 in. long, this latter part forming the shaft, and being at the lower end of the ingot as cast. The bottom and top excess, or crop metal, is then removed. The partially formed forging is placed upright in a 10,000-ton press, the shank down and held in a bolster, and the 119-in. length of 70 in. diameter upset to 100 in. long. The body is then forged to finished shape, and finally the shank is drawn out to form the shaft. The finished forging weighs 110,300 lb.

The forging is charged into the heat-treating furnace without having become cold after forging, and given a double annealing, first from a high heat and then from a low heat. It is then preliminarily rough-machined all over, the center or axial exploration hole shown in Fig. 4 being rough-bored at this time. The forging is then returned to the heat-treating furnace and given a second double treatment, first a normalizing and then a low-temperature anneal with slow cooling. It is then rough-machined to the general dimensions of Fig. 4. Following this it is returned to the furnace, and given a final low-temperature anneal with slow cooling. Such elaborate treatment is designed to impart to the forging the desired physical properties, and leave it free from injurious stresses and defects.

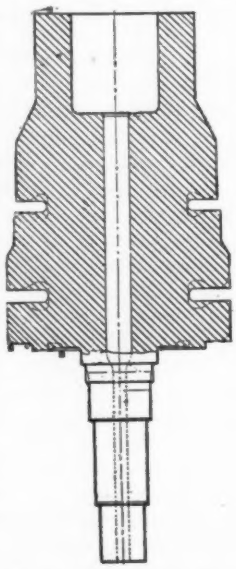

Fig. 4 Finished Forging for Coupling-End Half of a Turbine Spindle

Test pieces are then taken and tested. Upon completion of the tests the forging is returned to the lathe and the axial exploration hole bored to a smooth finish. A most careful examination is made of the walls of the axial exploration hole by means of a special periscope or bore searcher. This device is described and illustrated in detail in the original article. The question of joining the spindle halves comes next, and when this operation is completed the blading can be started.

The matter of balancing has to be considered now. The revolving element must be capable of accurate balance, and furthermore must remain in balance over the full range of operating temperatures for an indefinite period of time. A number of factors enter into the problem besides the stability of the turbine. It has long been held that if a turbine vibrates it is due to the poor balance or instability of the turbine rotor. We know now that it is very likely to be a resonant condition existing between the turbine rotor and its casing, and between the turbine and the foundation supporting it.

The use of solid forged spindles has added greatly to the stability of turbines and to their ability to stand abuse. After a turbine rotor has been completely finished, it is placed in a sensitive dynamic balancing machine and balanced. It is not necessary to balance all rotors to the same degree of accuracy. This depends on the speed at which the rotor is to operate, its mass, and the surface to which it is to be subjected.

When necessary, extreme degrees of accuracy may be obtained. For instance, the remaining unbalance at the balancing ring at each end of a rotor may be made as low as $^1/_2$ oz-in. per 1000 lb. weight of rotor, or the equivalent eccentricity of the center of gravity $^1/_{16,000}$ when unbalance is all static.

For large turbine rotors the remaining unbalance does not exceed 1 oz-in. per 1000 lb. weight of rotor. For example, a 35,000-lb. rotor by the above rule would be out of balance only 1.9 oz. at each end on an 18-in. radius, while the centrifugal force remaining unbalanced at normal speed would be 196 lb.

Before a rotor is placed in the balancing machine, the journals are checked for truth and roundness. Both must be within 0.0005 in. of absolute truth, or the journals are refinished.

After a spindle has been balanced it is placed in a heater box and subjected, while running, to a heat treatment, which seasons the spindle and relieves the remaining stresses to a very great extent. The process is as follows: The spindle is placed in an iron casing somewhat similar to a turbine cylinder. Here it is revolved in its own bearings by a small turbine at a speed of from 100 to 500 r.p.m. for a period of two hours. The exhaust of the heater box is then opened to the atmosphere, and saturated steam is admitted at an approximate rate of 10,000 lb. per hr. for a period of two hours. At the end of the two hours the steam is gradually superheated, raising the temperature slowly and uniformly throughout a period of six hours to a maximum of 700 deg. fahr. at the exhaust of the heater box while maintaining a flow of approximately 10,000 lb. per hr. The rotor during this time is still rotating at a speed of 100 to 500 r.p.m.

Following the heating-up process the overspeed tests and final heat treating are respectively carried out, whereupon the spindle is again tested for balance either in the balancing machine or in the heater box. (J. P. Rigsby, Large Turbine Engineer, South Philadelphia Works, Westinghouse Electric & Manufacturing Co., in *The Electric Journal*, vol. 24, no. 12, Dec., 1927, pp. 591–596, 7 figs., *d*)

MEASURING INSTRUMENTS (See Corrosion: An Investigation of the Corrosion of Metals with a Thermobalance)

METALLURGY (See also Machine Parts and Design: Air-Hardening Rivet Steels)

Aluminum and Aluminum Cast Irons

An investigation was made of aluminum and aluminum-chrome cast irons of the gray-iron type. The idea was that such irons in which the normal silicon content was partly or completely replaced by aluminum might show useful properties, especially in regard to resistance to growth and oxidation effects under high or fluctuating temperature and resistance to corrosion. Samples of the irons were made up with aluminum alone and aluminum and chromium together, both high silicon and low silicon having been tried. The general conclusion from these tests appears to be that there is no definite future for either of these materials. Although such irons have shown good properties in some ways, no properties have been discovered which cannot be obtained by other and simpler methods of treating cast iron. On the other hand, it has been found that irons containing aluminum are particularly difficult to cast provided sound and clean castings are desired. It has been also found that irons containing aluminum with or without chromium are quite unstable thermally. (Arthur B Everest, Ph.D., in *Foundry Trade Journal*, vol. 37, no. 592, Dec. 22, 1927, pp. 208–210, *e*)

Gases in Metals—in Particular, Nitrogen

A method has been developed for the determination of nitrogen in the gases evolved from metals fused in vacuum. This method of fusion is expected to determine also the uncombined nitrogen in the metal sample, and is expected to give a more nearly correct value for nitrogen in the analysis of materials containing silicon, titanium, and vanadium. (Louis Jordan and Jas. R. Eckman, in *Scientific Papers of the Bureau of Standards No. 563*, part of vol. 22, Oct. 18, 1927, pp. 467–485, 2 figs., *e*)

POWER-PLANT ENGINEERING (See also Thermodynamics: Heat Transmission Through Boiler Tubes)

Some Features of Steam-Turbine Development

THIS is an abstract of part of a symposium giving an annual review of power-plant progress. Stage bleeding appears to dominate station heat balance. At present in power-plant design it is a case of choosing between two unavoidable losses: the condenser loss of the heat in the steam, which necessitates no additional equipment, or loss of an equivalent amount of heat from the other sources which do involve additional equipment if the heat is not absorbed in the condensate. There is no uniformity regarding these various items. For instance, at Lauderdale the generator air cooler, generator oil cooler, and ejector condenser are all utilized, giving temperature rises of 9, 2, and 4 deg., respectively. Under full-load conditions in the average plant there is sufficient heat dissipated by the generator to heat the condensate from 10 to 13 deg. At Stanton, Des Moines, and Bayside the generator air cooler and ejector are used, while at Whippany the oil cooler and ejector condensers are utilized as feedwater heaters. Many other stations make use of ejector condensers only, the temperature rise throughout them averaging about 4 deg. fahr. There is little to substantiate the idea that condensate use for this service was being discontinued, although auxiliary water is usually provided for emergencies and a number of companies are using raw water on the intercooler and condensate on the aftercooler where extremely high vacuums are created.

Evaporators are now almost standard equipment, but there is little uniformity in their location in the station heat balance. In some places they follow the ejector condenser, in others, "high-heat-level" condensers immediately preceding the high-pressure heater are used. From a thermal standpoint there is little loss from evaporators regardless of their location or arrangement.

Deaerating heaters are being widely used. Reheating of the steam after it has completed a portion of its expansion has proved practical and successful. Stanton is the only reheat station which went into service in 1927. Now the new State Line station will use steam reheaters and the Powerton station now under construction will use standard and reheat boilers as installed at Stanton.

Viewing the development during the past year, there are several trends apparent. Stage extraction for feed heating and evaporation may now be considered universal. Motor drive, except in a few isolated cases, is practically universal, dependence being placed on various electrical sources either from the same station or through interconnection. Hotwell pumps are now designed to pump against a considerable head and force the condensate through several heaters, delivering it either direct to the suction of the boiler-feed pump or to an open storage heater immediately preceding the boiler-feed pump. This open heater is often operated at pressures above atmospheric and has some storage capacity to take care of slight load variations, although it is considered necessary to have a larger surge tank somewhere in the system. Many of the newer stations favor the introduction of water from the surge tank into the condenser hotwell, as at Morrell.

Adoption of motor-driven auxiliaries and of air preheaters has of course greatly widened the field for extraction steam. The motor drive affects the heat balance below 210 deg. by eliminating the auxiliary-turbine exhaust, and the air preheater affects the heat balance over 210 deg. fahr. by making it possible to send the feedwater to the economizer considerably above the temperature formerly considered feasible, or by making it possible to eliminate the economizer entirely, absorbing the heat of the flue gas in the preheater. The air preheater thus affects the economy of the station by increasing the temperature and efficiency of the furnace, by cooling the flue gas to any desired point, and by increasing the demand or utilization of exhaust steam.

The limit of turbine development is not in sight. A unit of 300,000 kw. is said to have been offered by one manufacturer. As a result of the operation of the first 3000-kw., 1200-lb.-pressure turbine at Lakeside, a second high-pressure unit rated at 10,000 kw. is being installed at Edgar, while an order has been placed for another 10,000-kw. 1200-lb.-pressure unit for an addition to the Northeast station in Kansas City.

The prospects for the mercury-vapor cycle were brightened by the success of the three-stage turbine installed in the Dutch Point Station at Hartford, Conn., late in 1926. It is claimed that the already remarkable record of 27 per cent thermal efficiency obtained at Columbia could be increased to 36 per cent if that plant were designed to operate on the mercury-steam cycle.

Stage bleeding is now accepted standard practice. The new 165,000-kw. unit at Philo will under base-load conditions be bled at five points for feedwater heating, the highest point at 365 lb. abs. and the lowest at 6.15 lb. abs. Steam will be delivered to the high-pressure element at 600 lb., 725 deg. fahr., and the initial pressure of the steam to the low-pressure element will be 126 lb. abs., 725 deg. fahr. after reheating.

It is said that it has recently been decided that in the future no turbines of less than 50,000 kw. output will be installed in Chicago and adjacent territory. The reason for using the large machines is not so much better fuel economy as it is reduced plant investment and the desire to keep the total plant capacity in as few units as possible.

The 104,000-kw. unit at Crawford was designed as a base-load unit with the leaving loss reduced to a minimum. It is approximately 1 per cent of the most economical load and $1^3/_4$ per cent of the maximum load, each figure assuming steam extraction at four points for feedwater heating. Steam is supplied to the high-pressure element at 565 lb. abs., 725 deg. fahr., and is expanded to about 40 lb. abs. It is then reheated by means of a steam reheater to 500 deg. fahr. before entering the double-flow intermediate element. One-third of the steam flow then passes in one direction and is completely expanded, while two-thirds of it passes in the opposite direction, expanding to 8 lb. abs. It is then passed to the double-flow low-pressure element which is in the same line of shafting as the intermediate element. By this arrangement steam is exhausted to six condensers at three points.

Trends toward higher speeds are evident, and an 89,412-kva. machine has been designed for 1800 r.p.m. Fifteen hundred revolutions per minute for 25- and 50-cycle and 1800 r.p.m. for 60-cycle machines are now standard for the larger sizes, while units of 10,000 kw. have been built for 3600 r.p.m. Temperatures remain about the same as during last year, and have been limited in this country to 750 deg. fahr. with the usual operating temperatures ranging from 700 to 725. It is reported that these temperatures have been exceeded in several European plants, although there is nothing to indicate that higher temperatures are being contemplated in this country before the results of research in this direction now under way are known. Undoubtedly there will be an endeavor to resort to higher temperatures later, but whether this increase will be in steps, by using special alloy steel, or whether there will be a gradual increase from year to year, cannot be predicted at present. (Abstracted from the Annual Review Number of *Power Plant Engineering*, vol. 31, no. 24, Dec. 15, 1927, pp. 1320–1326, illustr., *g*)

RAILROAD ENGINEERING

Back-Pressure Gages and Limited Cut-Off

FROM replies to a questionnaire sent out to the mechanical officers of several railroads it would appear that there is still a good deal of uncertainty as to the use of back-pressure gages. There is an agreement that back-pressure gages are of material assistance in determining nozzle sizes; many believe that the gage helps in determining irregularities in valve setting, and enables enginemen to detect the formation of a vacuum in the cylinders while drifting, thus avoiding the scoring of cylinders. The back-pressure gage also apparently holds in determining reverse-gear creeping. In other respects there is still a good deal of uncertainty although the consensus of opinion is that the back-pressure gage results in fuel and water economy, enables enginemen to work locomotives to better advantage, prevents abuse of locomotives, and enables traveling engineers to demonstrate more clearly how to obtain the best results with locomotives. Regarding limited cut-off the committee pointed out that its use entails no radical change in the design of the locomotive. It means that the piston pressure must be increased, which in turn calls for an increase in the weight of reciprocating parts.

Furthermore, "the design features which differ from the ordinary locomotive, but which cause very small differences in weight and cost, are in increased steam lap on the valve, a small auxiliary port cut through the valve bushing at each end of the steam chest, and a change in the ratio of the combination lever to compensate for the increased steam lap."

The committee reported that from actual tests on a large eastern road, a water saving of 11 per cent to 38 per cent was effected by the limited-cut-off locomotive as compared with the conventional locomotive, depending on the load and speed. The committee drew the following general conclusions:

"From this it may be safely inferred that the limited-cut-off locomotive should produce a coal and water saving in heavy slow-freight service of about 20 per cent and in fast-freight service from 10 per cent to 15 per cent. In passenger service we do not believe there is a place for the limited-cut-off because of the negative effect due to increased weight of reciprocating parts of 10 per cent or less."

Only a small amount of information was submitted in response to the committee's questionnaire sent to 20 railroads. Four roads, however, reported using limited-cut-off locomotives with substantial economies. None of the roads reported the use of the limited-cut-off in passenger service. (Report of committee read by A. T. Pfeiffer, Chairman, at the Traveling Engineers' Convention, abstracted through *Railway Mechanical Engineer*, vol. 101, no. 11, Nov., 1927, pp. 720–721; the part dealing with Diesel electric locomotives on the Canadian National being on pp. 719–720, *pg*)

Double Power Tender Trucks for Missouri Pacific

THESE trucks were devised to meet the problem of providing additional unit motive power for heavy-duty hump-yard switching service at Dupo, Ill. Two locomotives, one of the 2–8–2 type and one of the 2–10–2 type, were equipped with new large-capacity tenders, each having two 6-wheel power tender trucks or auxiliary locomotives. These trucks have 10-in. × 12-in. cylinders, and six wheels on each truck for transmitting power, the wheels being 36 in. and the gear ratio 2.25. By this device the tractive force of one of the locomotives was raised from 94,400 lb. to 122,400 lb. and that of the other from 81,600 to 111,600 lb. The boilers were found to be capable of supplying enough steam for the additional engines. While the available tractive force of the locomotives was increased respectively 30 and 37 per cent, the capacity of the locomotives in tons handled over the hump increased 50 per cent. This is due to the longer trains which permit the locomotive and some of the cars to be on the level or on a very slight grade at the bottom of the hump at the time the first cars are being pushed over. The special tender underframes and piping are briefly described. The auxiliary locomotive automatically goes into engagement upon the opening of a special throttle valve controlled by the engineman, and disengages upon closing of the throttle valve, which makes its operation and control comparatively simple. (*Railway Mechanical Engineer*, vol. 102, no. 1, January, 1928, pp. 13–15, 3 figs., *d*)

STEAM ENGINEERING (See also Machine Shop: Building Large Steam-Turbine Spindles; Machine Parts and Design: Air-Hardening Rivet Steels)

Standardization of Dished Heads in Respect to Internal Pressure

THE question of unanchored dished heads in respect to their ability to resist internal pressure will be definitely solved only when the heads themselves are standardized. This is quite convenient to do. The question of standardization has to be considered from three points of view: width of head, depth of head, and shape of meridian of head.

I—Width of Heads

In the construction of closed cylindrical containers extensive use is already made of heads specified in pricelists. There appears to be a possibility of reducing for future use the number of standard heads so as to make it even smaller than the number listed in trade catalogs today, and do this without interfering with the engineering side of construction. It would appear to be sufficient to vary the diameter up to 60 cm. (say, 24 in.) in steps of 5 cm. (say, 2 in.); from 60 up to 120 cm. (say, 48 in.) in steps of 10 cm. (say, 4 in.), and from then on in steps of 20 cm. (say, 8 in.). The number of dies will then be reduced materially. This will contribute to reduction of cost of manufacture and hence price of the heads.

II—Depth of Head

The most important question is probably how deep the head should be, and the author refers to tests on this subject made in Stuttgart by C. Bach, in Düsseldorf by Siebel and Körber, and in Zurich under his own direction. These tests have substantially clarified the problem of the stresses to which heads of various depths and shapes are subject to. As a result of all of this work certain rules as to the shape and calculation of heads have been established and already incorporated into some official acts. Even assuming that the problem of design of heads has not yet been completely determined theoretically, this is not very important, particularly as one knows today fairly clearly how to protect the heads from failure in actual operation.

There is a general agreement that the hemispherical head satisfies in a very far-reaching manner safety requirements even when its thickness is below that of the shell. The fact that hemispherical heads are but seldom used is due to the difficulty and expense of their manufacture, and also to the fact that they project far over the shell, which, in most cases, is not desirable. The saving in material because of the smaller thickness becomes here a secondary consideration, particularly since as a matter of fact, from the point of view of securing a better connection, it is advisable to use plate of equal thickness in the shell and head.

For some time now heads have been used as proposed by Diegel, i.e., with an elliptical meridian where the depth (or height) $h = \frac{1}{4} D$ or $k = 2$. Here D is the diameter and $k = a/b$ or the "depth ratio," where a and b are respectively the major and minor semi-axes of the ellipse, so that $D = 2a$ and $h = b$. In this type of head the thickness of plate is also less than that of the plate in the shell. Since, however, the cost of manufacture of this type of head is still quite high, it is desirable to use in boiler and tank construction heads still flatter.

The case where the plate thickness in the head is approximately equal to that in the shell is (according to the investigations of the author[1]) covered for basket-shaped and elliptical heads by the equation:

$$k = a : b \eqsim 2.5 \qquad [1]$$

The extra weight which such a design of a head involves as compared with the weight when $k = 2$, is amply compensated in so far as the cost of production is concerned, by the greater ease of manufacture of the pieces.

III—Shape of the Meridian of the Head

When the meridian has the shape of an ellipse, its curvature is determined by a mathematical law, as there can be only one ellipse for given values of a and k. The situation is, however, entirely different in the case of a basket shape, even if the latter, as in the simplest case, is composed of two circular arcs. In such a case one of the radii is called the radius of the flange and the other the radius of arcing. These are designated by r and R, respectively. For given values of a and k or b, an infinitely large number of meridians is possible with the terminal values on one hand $r = 0$, $R = R_{\min.}$, and on the other, $r = b$, $R = \infty$. The question is now whether all the meridians possible are equally suitable for purposes of head design. It is clear at once that the two terminal-value meridians cannot be considered in this connection, as the most suitable basket shape appears to be the one in which the flange diameter is as large as possible and the arc diameter as small as possible. Because of this the ratio r/R (hereafter called the ratio of curvature) will have its maximum value for given values of a and b. Calculation shows that the following equation satisfies this requirement:

$$\left(\frac{r}{R}\right)_{\max.} = \frac{\sqrt{k^2+1}-k}{\sqrt{k^2+1}-1} \qquad [2]$$

The line connecting the centers of curvatures in this case—but only when the above condition is satisfied—is normal to the diagonals in the right angle a b. This basket arc—and this is the important thing—comes nearest to the ellipse of the values a and k.

The tests referred to above have definitely established that the stresses along the meridian are more favorably distributed in an elliptical head than in a basket-shaped head, and in particular, smaller stresses occur in the flange in the former case than in the latter. The result of this is that it appears to be necessary to design basket-shaped heads so that they will approach as nearly as possible elliptical shapes. This occurs when the ratio r/R attains the value given by Equation [2]. The radii r and R may be then directly computed from

$$r = \frac{a^2+b^2-a\sqrt{a^2+b^2}}{a+b-\sqrt{a^2+b^2}} = a\,\frac{k^2+1-k\sqrt{k^2+1}}{k^2+k-k\sqrt{k^2+1}} = a\,r_0 \qquad [3]$$

$$R = \frac{a^2+b^2-b\sqrt{a^2+b^2}}{a+b-\sqrt{a^2+b^2}} = a\,\frac{k^2+1-\sqrt{k^2+1}}{k^2+k-k\sqrt{k^2+1}} = aR_0. \qquad [4]$$

For a given value of k the radii r_0 and R_0 have constant values. The values given in the table [in the article] are considered to be important. It would appear, therefore, that there is no trouble in devising the best possible shape for a basket, as the flange and arcing diameters can be easily determined. The German technical handbook Hütte, vol. 3, gives a graphical method for doing this.

The dimensions of a, b, r, and R should be measured up to one-half of the plate thickness. This should be observed also in the case of the dies, and in making them half of the plate thickness should be indicated. Since, however, there are heads of various thicknesses, those used most frequently should be considered in this case and the inexactness in the case of the head having a different thickness may be entirely neglected. Hence in standardizing heads the values of a and b may be expressed in round figures. This will not always be possible for the values of r and R, but even this is immaterial as shown by the following example. Assume that the diameter of a head $D = 2a = 200$ cm. (80 in.). With $k = 2.5$ we shall have $b = a/k = 40$ cm. (16 in.). The flange radius is then $r = a\,r_0 = 100 \times 0.257 = 25.7$ cm. (9.8 in.), and the arcing diameter $R = a\,R_0 = 100 \times 2.258 = 225.8$ cm. (88.8 in.).

IV—Official Rules and Regulations

The Swiss regulations governing material and construction in stationary steam boilers, in a supplement dated March, 1927, prescribed that the height h of a head (designated as b in this discussion) should not be less than $0.2\ D = D/5 = a/2.5$. It is in this way that the condition $k = 2.5$ is established. The author's proposal to make $k = 2.5$ is therefore within the limits of the official order, even if at the very border line thereof. Further regulations prescribe that $r \geqq \rho'$ and $R \leqq \rho''$ where ρ' and ρ'' are respectively the small and large radii of curvature of the ellipse. In this respect the author's proposal still very nearly satisfies the official requirements. If in the above-cited example of a basket-shaped head we use $a = 100$ cm. (39.37 in.), $k = 2.5$, and hence $b\ (= h) = 40$ cm. (15.74 in.). The regulations then demand the following: $r \geqq \rho' = b^2/a = 25$ cm. (9.84 in.) and $R \leqq \rho'' = a^2/b = 200$ cm. (78.74 in.). It is suggested that these values be compared with the values for r and R of the meridian of such a head. A further requirement calls for $r \geqq 0.1\ D = a/5$, and $R = D = 2a$, where by D is meant the external diameter; $a/5$ in the present example is 20 cm. (78.74 in.). The regulations governing the materials and design given in the Appendix of March, 1927, to the rules of October, 1926, and applying to the manufacture of a basket-shaped head will have an infinitely large number of possibilities notwithstanding the limits prescribed. On the other hand, it is advisable, or still better, necessary, to select one construction and that the strongest one, apart from considerations of expediency. Because of the greater safety of the heads it is possible to produce very great simplification of the official rules, which is really the spirit of standardization.

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[1] In making this calculation the author used as a basis the equation

$$s = 1.65\,\frac{p\,a\,k}{K\,z}\;\frac{20\,r/R+3}{20\,r/R+1}$$

in centimeters. The situation is applicable to basket-shaped arcs and is Equation 52 in the book "Ueber die Festigkeit der gewölbten Böden." This equation was designed to determine the maximum stresses in the surface of a head. An exact calculation of internal stresses is scarcely possible as there is considerable divergence between present theories. A head computed in accordance with the above equation is sufficiently thick not to be imperiled by internal stresses. The member $\frac{20\,r/R+3}{20\,r/R+1}$ implies that the minimum thickness of a head is obtained when the meridian has the most suitable shape for given values of a and b, or D and h. If this condition is not satisfied, the plate thickness is increased.

V—Cast Heads

It may be added that for cast heads k should be selected so as to be less than 2.5—at most 2, and still better 1 (hemispherical head). Furthermore, if one selects the basket arc as a meridian the most advantageous form should be used for cast heads.

VI—Heads for Storage Containers

In addition to heads for boilers and pressure vessels, there are also a number of storage and freight containers which do not have to carry any pressure. Nevertheless the walls should have a certain thickness in order to obtain the necessary stiffness and protect the vessel from external forces. For such containers as these a depth ratio of $k = 5$ appears to be satisfactory here. Should heads be standardized generally it will be necessary to include this kind as well. The steps in which the diameters would be standardized would have to be different and greater. In accordance with the rest of the reasoning in this article it is proposed here to recommend as a shape of meridian only the most favorable one, that is, the one in which r / R = maximum. (E. Höhn, Chief Engineer of the Swiss Association of Steam Boiler Owners in *Zeitschrift des Bayerischen Revisions-Vereins*, vol. 31, no. 24, Dec. 31, 1927, pp. 263–265, *pA*)

THERMODYNAMICS

Heat Transmission Through Boiler Tubes

IN THE past boiler heat-transmission data, which have been obtained under laboratory control methods, have been determined on the "fire-tube" type of apparatus where the boiling phenomena and water circulation on the wet side of the heating surface probably did not duplicate the conditions which exist in an actual power boiler. The objects of this investigation were to obtain heat-transmission data under conditions similar to those existing in an actual water-tube boiler and to study the phenomena of water circulation under the same conditions.

The water velocity of the "downcomer" header of the apparatus was determined by two pitot tubes connected to a venturi-meter manometer. One tube pointed upstream and the other downstream.

These tubes were calibrated in place, using a kerosene-diluted solution of chlorabenzene (C_6H_5Cl) as a manometer fluid, and water at three different temperatures, namely, 56, 121, and 166 deg. fahr.

The expression

$$V = \frac{1.032\, h^{0.463}}{t^{0.0935}} \quad \ldots\ldots [1]$$

where V = water velocity in ft. per sec.
h = reading of manometer in inches of chlorabenzene at 70 deg. fahr., and
t = water temperature in deg. fahr.

was found to express the results obtained and was used to compute the water velocities on all tests. (The calibration equation for the water velocity is further discussed in Par. 27, p. 30 of the original paper.)

The amount of heat transmitted by the tube was calculated from an equation given in the original article which represents the total heat as the sum of the various items. Certain elements in this calculation, for instance the calculation of the radiant-heat absorption, is interesting.

It was found that the coefficient of heat transmission varied considerably under the influence of at least four factors, and certain empirical formulas were developed for the calculation of these coefficients. The relations between the coefficient of heat transmission and water velocity are generally discussed and a formula given to show broadly their relationship. The circulation phenomena are of particular interest.

When the water in the apparatus is first heated, a convection velocity results because of the density difference between the hot water in the "upheader" and the cold water in the "downheader." This convection velocity tends to decrease as the water temperature in the apparatus becomes higher. This is because the difference in density between the two legs becomes less as the temperature increases on account of the fact that the rate of decrease of water density decreases as the temperature increases and therefore the difference in weight between the hot and cold legs for a 2-deg. temperature difference at 400 deg. is less than for a 2-deg. temperature difference at 200 deg.

In addition to the convection effect, at a certain temperature condition in the heating of the water the "bubble" effect begins. This phenomenon is determined in the air-lift pump and consists in the decreasing of the density of the fluid in the upheader by the formation of steam bubbles.

This bubble effect is caused by two distinct operations: (1) Part of the water heated to the saturation temperature at the bottom of the upheader may flash into steam as it rises in the upheader, due to the decrease in static pressure of the water. (2) The water in the tube may be heated at a greater rate than can be absorbed by the water alone, and hence steam bubbles may be formed in the tube itself.

It was found that the water velocity in the tube has only a slight effect on the overall coefficient of heat transmission; the water velocity in the inclined tube of the apparatus varies as the steam rate and total energy input and tends to approach a practical maximum at slightly over 3 ft. per sec.; the water velocity is affected by the steam pressure as indicated by an equation given in the original article (Equation [17], p. 49); the temperature gradient from the flue gas to the water in the tube varies with the flue-gas temperature, the rate of gas flow, and the steam pressure in accordance with curves given in the original article (Fig. 17, p. 50). Additional tests were carried out with the tube coated with scale. The results are given in the form of a table and would indicate that if heat radiation is present the reduction in heat transmission due to scale will be greater than where there is no heat radiation, because of the fact that radiant heat is not absorbed by gases in thin films, and therefore the gas film on the outside of the tube offers practically no resistance to radiation. [Huber O. Croft (Mem. A.S.M.E.) in *University of Illinois Bulletin*, vol. 25, no. 5 (*Engineering Experiment Station Bulletin No. 168*), Oct. 4, 1927, pp. 3–55, 17 figs., *e*]

VARIA

Air Rights

BY "AIR RIGHTS" the author does not mean anything connected with aeronautics, but the right of an owner of property—in particular, railroad property—to the use of the space above it.

The matter is at present attracting considerable attention in Illinois, because there are two applications for approval before the Illinois Commerce Commission, one covering the development of air rights over the Chicago and Northwestern Railroad at Kinzie St., Chicago, in order to make possible the construction of a large warehouse for Marshall Field & Co., and the other the application of the Chicago Union Station Co. to obtain permission to sell the air rights required for the construction of a building for the *Daily News* to occupy a whole block. A recent law of Illinois gives to the railroads the right to make use of or to sell or to exploit air rights whenever the exploitation of such

rights does not interfere with the use and the operation of the railroad underneath, and it is the duty of the State Commerce Commission to see that the railroads are protected in their public functions and not victimized.

An example of a big development of air rights is represented by the New York Central Passenger Terminal in New York where these rights affect many streets and an area utilized for buildings of approximately 1,000,000 sq. ft.

The air rights are defined as applying to the space above a plane of clearance over railroad tracks and facilities, such space being capable of utilization for the construction of streets and buildings in the same manner as if the railroad facilities did not exist. Examples are cited where railroads have made use of what are called air rights long before these rights became as valuable as they are now. When railroads were operated by steam power this produced limitations which made the utilization of air rights often an impossibility. It was not until electric operation came into effect that it became possible to tackle the problem with comparative freedom. Partial use of air rights can be made, however, even with steam operation, and as a matter of fact it is being done to a surprisingly large extent. Smoke removal is here a problem, and often the results are not quite satisfactory. In the case of the *Daily News* Building, special precautions have been taken, and a very extensive and elaborate ventilating installation is being provided for the reason that the building will lie directly over station, tracks, and platform.

Among the conclusions arrived at by the author are the following:

The utilization of air rights creates difficult engineering problems, but not beyond the ordinary good practice of capable designers, and their solution does not involve the use of prohibitive construction methods.

The operating conditions on the railroads affected are not unduly burdensome as a result of air-right uses, and in fact are in many respects improved.

From a user's standpoint, air rights offer greater possibilities for development than adjoining land under separate ownership.

The development of air rights offers possibilities of creating orderly and adequate civic improvements.

Air rights are not economically usable unless the adjoining land has a greater value than at least $25 per sq. ft.

There cannot be a fixed ratio between the value of the level occupied by the railroad and that of the air right, the former being almost a constant, the latter a variable for all locations. (Joshua D'Esposito, Consulting Engineer and former Chief Engineer, Chicago Union Station Co., in *Journal of the Western Society of Engineers*, vol. 32, no. 10, Nov., 1927, original paper, pp. 361–366, and discussion, pp. 366–371, *g*)

CLASSIFICATION OF ARTICLES

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general; *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

Cooperative Railroad Course at M.I.T.

THE creation of a cooperative course in railroad operation, in which scientific education at Massachusetts Institute of Technology will be combined with fundamental training in modern transportation practice on the Boston & Maine Railroad, is announced by Dr. Samuel W. Stratton, president of the Institute.

The course has been under consideration for nearly a year, during which committees representing the railroad and the Institute made an intensive study of the scope of the training to be undertaken.

The completed plan places emphasis on instruction in extension, improvement, and operation of existing lines rather than construction of new lines. Much time will be given to the study of passenger and freight traffic, steam-locomotive practice, auxiliary means of transportation, and traffic problems. Instruction in science and experience in operation will be alternated to assure efficient application of technical training in practice.

The course will also include the fundamental subjects of civil and electrical engineering, such as bridge building, earth works; electrical equipment, including signals, communicating systems, and train lighting; as well as the characteristics of terminal and trunk-line electrification.

All the facilities of the Boston & Maine's great freight-classification system and the new $10,000,000 passenger-terminal development will be available for instruction in the operating part of the course. Training in operation, maintenance, and repairs of locomotives and cars will be given at the Billerica shops. Studies in administration, including company policy, accounting, stores, testing materials, and research, will be given in the executive department of the railroad.

The Institute work consists of four years of undergraduate instruction, including one summer at Camp Technology, the civil-engineering field school in Maine, a full year of post-graduate work, and a special summer term arranged to meet the requirements of the plan. The work on the railroad amounts to a year and a half, and the period of alternation of time in railroad employment and at the Institute begins at the end of the second year of undergraduate instruction.

Discussing the need for such a course and the value of the plan of cooperative training, George Hannauer, president of the Boston & Maine, said:

> Although my education was in the School of Hard Knocks, I have always felt that, had I had a technical training, I might have ascended each rung of the ladder more securely and with somewhat less effort. Conversely, some technically trained men after graduation have difficulty in adjusting themselves and getting started up that same ladder. It was my conviction that the best of college and the best of the School of Hard Knocks should be combined that led to my keen interest in establishing a cooperative course in which the Boston & Maine Railroad would join with the Massachusetts Institute of Technology, the school of premier standing in its field.
>
> I sincerely hope and believe that the young men engaged in this course will receive not only a broad technical training, but will gain, by practical work in railroad service, the further advantage of early application of technical theory. Certainly after such a course the graduate should be the better fitted to enter railroading directly, with knowledge of methods and practices and the knack, gained through contacts, of working to best advantage with other men.

Each student accepted for the course will become a regular employee during his work on the railroad and will be paid a salary by the company. In order that he may gain as much knowledge as possible of railroad operation, his working assignments will be carefully planned on sound educational principles. He will be held as accountable as any other workman for good work and right spirit.

Cast-Iron Long-Turn Sprinkler Fittings

Standards for Screwed and Flanged Fittings for Maximum Hydraulic Working Pressures of 150 and 250 Lb. per Sq. In. Gage

STANDARDS for cast-iron long-turn sprinkler fittings designed for maximum hydraulic working pressures of 150 and 250 lb. per sq. in. gage have just been completed. This work was done by the Sectional Committee on the Standardization on Pipe Flanges and Flanged Fittings, organized under the procedure of the American Engineering Standardization Committee. The Sponsors for this project are the Heating and Piping Contractors' National Association, the Manufacturing Standardization Society of Valve and Fittings Industry, and The American Society of Mechanical Engineers.

These standards are now passing through the final stages necessary to make them "American Standard." Copies in page-proof form are now available and may be procured by addressing C. B. LePage, Assistant Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y.

Below are given the introductory notes of these standards, together with Tables 1–4. Table 5, on general dimensions for a working pressure of 250 lb. per sq. in., is omitted.

INTRODUCTORY NOTES

1 *Pressure Ratings.* These standards shall be known as the "American 150 and 250 Lb. Cast-Iron Long-Turn Sprinkler Fittings," said pressure designations being the maximum recommended ratings.

The following momentary test pressures are to be applied by insurance companies, underwriters, etc. only when passing upon the acceptability of this material for sprinkler service. This test is applied to representative fittings selected at random, the fittings being tested to destruction:

TABLE 1 PHYSICAL AND CHEMICAL (CAST TEST BAR) REQUIREMENTS FOR CAST IRON FOR FITTINGS AND FLANGED FITTINGS

Casting	Tensile strength in lb. per sq. in. (minimum)	Per cent sulphur (not over)
Light[1]	20,000	0.12
Medium[2]	21,000	0.12
Heavy[3]	24,000	0.12

[1] Light Castings—those having any section less than 1/2 in. in thickness.
[2] Medium Castings—those not included in either the Light or Heavy classes.
[3] Heavy Castings—those in which no section is less than 2 in. in thickness.

The 150-lb. fittings, sizes 2 1/2 to 6 in., inclusive, shall be able to resist a momentary pressure of 750 lb. per sq. in., and the 8-in. size shall be able to resist a momentary pressure of 600 lb. per sq. in.

The 250-lb. fittings, sizes 2 1/2 to 6 in., inclusive, shall be able to resist a momentary pressure of 1250 lb. per sq. in. and the 8-in. size shall be able to resist a momentary pressure of 1000 lb. per sq. in.

2 *Size.* The term "size" shall be used in all the following tables to indicate the nominal inside diameter of port. These specifications are for long-turn cast-iron fittings for sizes 2 1/2 in. to 8 in., inclusive, for use in sprinkler work inside of buildings.

The sizes smaller than 2 1/2 in. are the American 125-Lb. and 250-Lb. Cast-Iron Screwed-Fittings Standards, while the 8-in. sizes are the American 125- and 250-Lb. Cast-Iron Flanged-Fittings Standards.

3 *Markings.* Each fitting produced with the intent of meeting the specifications of these "American Cast-Iron Long-Turn Sprinkler Fittings" shall have marks cast on them indicating legibly:

(1) Maker's name or trademark

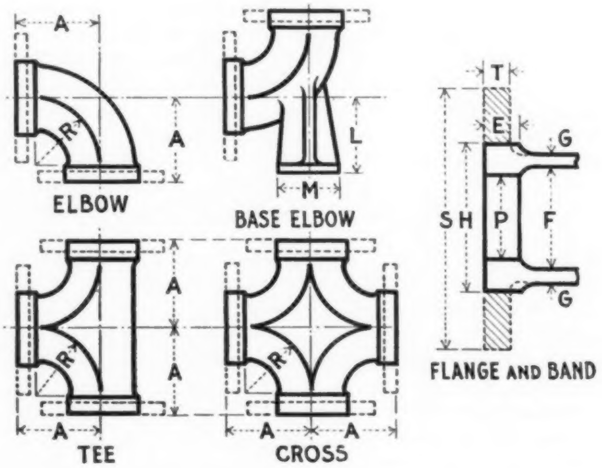

Fig. 1

TABLE 2 GENERAL DIMENSIONS FOR CAST-IRON LONG-TURN FITTINGS FOR A MAXIMUM HYDRAULIC WORKING PRESSURE OF 150 LB. PER SQ. IN.

(See Fig. 1. All dimensions given in inches)

		Sizes 2	2 1/2	3	3 1/2	4	5	6	8[1]
A	Center to end or face	Outlets for reducing sizes	4 1/2	5	5 3/4	6 1/2	7 1/2	9	9
L	Center to base		4 1/2	4 7/8	5 1/4	5 1/2	6 1/4	7	8 3/8
S	Diameter of flange	6	7	7 1/2	8 1/2	9	10	11	13 1/2
T	Thickness of flange	5/8	11/16	3/4	13/16	15/16	15/16	1	1 1/8
M	Diameter of base flange	....	4 1/2	5	5	6	7	7	9
F	Inside diameter of body, Maximum	2.445	2.975	3.600	4.100	4.600	5.663	6.725	Nominal
	Inside diameter of body, Minimum	2.375	2.875	3.500	4.000	4.500	5.563	6.625	
P	Diameter of port for Screwed, Flanged	Rough tapping diameter							
H	Band diameter,[2] minimum	3.28	3.86	4.62	5.20	5.79	7.05	8.28	....
E	Band width,[2] minimum	0.84	0.94	1.00	1.06	1.12	1.18	1.28	....
G	Metal thickness, minimum	0.22	0.30	0.32	0.34	0.36	0.41	0.46	0.62
R	Radius of sweep, minimum	....	3.50	3.87	4.53	5.19	6.06	7.44	....
	Length of thread,[3] minimum	0.75	0.92	0.98	1.03	1.08	1.18	1.28	....
	Diameter of bolt circle	4 3/4	5 1/2	6	7	7 1/2	8 1/2	9 1/2	11 3/4
	Number of bolts	4	4	4	8	8	8	8	8
	Diameter of bolts	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4
	Diameter of drilled bolt holes[4]	3/4	3/4	3/4	3/4	3/4	7/8	7/8	7/8
	Style elbows recommended for stock	....	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C	....
	Style tees recommended for stock	....	G, H, L	G, H, L, N	G, H, L, N	G, H, L, N	G, H, L, N	G, H, L, N	
	Style crosses recommended for stock	....	....	....	P	P	P	P	....

[1] The 8-in. size is an American Standard 125-lb. cast-iron flanged fitting.
[2] Fittings may be banded or have equivalent bead and band.
[3] The minimum length of thread shall be measured to include countersink.
[4] Drilling templets are in multiples of four, so that fittings may be made to face in any quarter and bolt holes straddle the center line. For bolts smaller than 1 3/4 in. the bolt holes shall be drilled 1/8 in. larger in diameter than the nominal diameter of the bolt. Holes for bolts 1 3/4 in. and larger shall be drilled 1/4 in. larger than nominal diameter of bolts.

(2) Identification symbol by means of which this line of fittings can be distinguished
(3) Working pressure.

4 *Types.* The various styles of elbows, tees, and crosses included in this standard are shown in Fig. 1.

When one end of the fitting is flanged, it shall be the largest opening unless otherwise specified.

5 *Material.* The dimensional standards for cast-iron fittings covered herein are based on a high-grade product. The physical and chemical requirements shall be in accordance with Table 1. These requirements are recommended in the absence of similar data in these specifications of the A.S.T.M. applicable to cast iron intended for the manufacture of pipe flanges and fittings, pending the preparation of an acceptable specification.

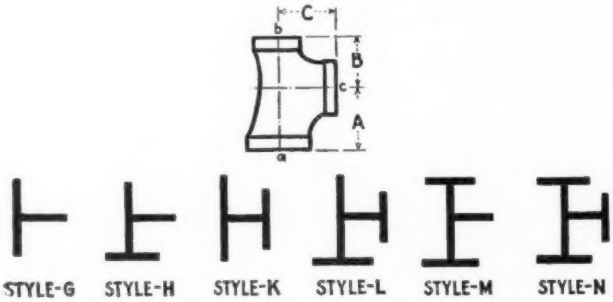

FIG. 2

TABLE 3 DIMENSIONS OF CAST-IRON REDUCING TEES FOR A MAXIMUM HYDRAULIC WORKING PRESSURE OF 150 LB. PER SQ. IN.

(See Fig. 2. All dimensions given in inches)

Nominal pipe sizes a × b × c	Center to end A	B	C	Styles recommended for stock
2 1/2 × 2 1/2 × 3 1/2	5 1/8	5 1/8	4 11/16	G
2 1/2 × 2 1/2 × 3	4 13/16	4 13/16	4 9/16	G, K
2 1/2 × 2 × 3	4 13/16	4 1/2	4 9/16	G
2 1/2 × 2 × 2 1/2	4 1/2	4 3/16	4 1/2	G, H
3 × 3 × 4	5 1/2	5 1/2	5 3/16	G
3 × 3 × 3 1/2	5 1/4	5 1/4	5	G, K
3 × 3 × 2 1/2	4 9/16	4 9/16	4 13/16	G, H
3 × 2 1/2 × 3 1/2	5 1/4	5 1/8	5	G
3 × 2 1/2 × 3	5	4 13/16	5	G, H
3 × 2 1/2 × 2 1/2	4 9/16	4 1/2	4 13/16	G, H
3 × 2 × 3 1/2	5 1/4	4 13/16	5	G
3 × 2 × 3	5	4 1/2	5	G
3 1/2 × 3 1/2 × 5	6 9/16	6 9/16	5 15/16	G
3 1/2 × 3 1/2 × 4	6	6	5 13/16	G, K
3 1/2 × 3 1/2 × 3	5	5	5 1/4	G, H
3 1/2 × 3 1/2 × 2 1/2	4 11/16	4 11/16	5 1/8	G, H
3 1/2 × 3 × 4	6	5 1/2	5 13/16	G
3 1/2 × 3 × 3 1/2	5 3/4	5 1/4	5 3/4	G, H
3 1/2 × 3 × 3	5	5	5 1/4	G, H
3 1/2 × 3 × 2 1/2	4 11/16	4 9/16	5 1/8	G
3 1/2 × 2 1/2 × 4	6	5 3/8	5 13/16	G
3 1/2 × 2 1/2 × 3 1/2	5 3/4	5 1/8	5 3/4	G
3 1/2 × 2 1/2 × 3	5	4 13/16	5 1/4	G
*3 1/2 × 2 1/2 × 2 1/2	5	4 13/16	5 1/4	G
3 1/2 × 2 × 3 1/2	5 3/4	4 13/16	5 3/4	G
*3 1/2 × 2 × 3	5 3/4	4 13/16	5 3/4	G
4 × 4 × 5	7 1/8	7 1/8	6 5/8	G
4 × 4 × 3 1/2	5 13/16	5 13/16	6	G, H, L
4 × 4 × 3	5 3/16	5 3/16	5 1/2	H
4 × 3 1/2 × 4	6 1/2	6	6 1/2	G, H, L
4 × 3 1/2 × 3 1/2	5 13/16	5 3/4	6	G, H
4 × 3 × 4	6 1/2	5 1/2	6 1/2	G
4 × 3 × 3 1/2	5 13/16	5 1/4	6	G
4 × 3 × 3	5 3/16	5	5 1/2	G
4 × 2 1/2 × 4	6 1/2	5 3/8	6 1/2	G
*4 × 2 1/2 × 3 1/2	6 1/2	5 3/8	6 1/2	G
5 × 5 × 6	8 1/16	8 1/16	7 9/16	G
5 × 5 × 4	6 5/8	6 5/8	7 1/8	H, L
5 × 4 × 5	7 1/2	7 1/8	7 1/2	K
5 × 3 1/2 × 5	7 1/2	6 9/16	7 1/2	G
5 × 3 × 5	7 1/2	6 1/16	7 1/2	G, K
5 × 2 1/2 × 5	7 1/2	6	7 1/2	G
6 × 6 × 5	7 9/16	7 9/16	8 1/16	H, L, N
6 × 6 × 4	6 11/16	6 11/16	7 11/16	H, N
6 × 5 × 6	9	8 1/16	9	G, H, K
6 × 5 × 5	7 9/16	7 1/2	8 1/16	H
6 × 4 × 6	9	7 11/16	9	G, K
6 × 3 1/2 × 6	9	7 3/16	9	G
6 × 3 × 6	9	6 11/16	9	G

* These fittings may be made by bushing in the sand the sizes listed immediately above them.

6 *Facings.* All the flanges for the 150-lb. standard shall be plain-faced. All the flanges for the 250-lb. standard shall have a raised face 1/16 in. high of the diameters given in Table 5. The raised face is included in the flange thickness and center-to-face dimensions.

7 *Bolting.* Drilling templets shall be in multiples of four, so that fittings may be made to face in any quarter. Bolt holes shall straddle the center line and shall be drilled 1/8 in. larger than the nominal diameter of bolts. Drilling templets are those of the American 125-lb. and 250-lb. Cast-Iron Flanged-Fittings Standards.

Bolts and nuts shall be threaded with the American (National) Standard Screw Thread.[1] Coarse Thread Series, Free Fit (Class 2).

Bolts shall be of steel with standard "Rough Square Heads" and the nuts shall be of steel with standard "Rough Hexagonal" dimensions; all as given in the "Tentative American Standard on Wrench-Head Bolts and Nuts and Wrench Openings."

8 *Metal Thickness.* It is recognized that some variations are unavoidable in the making of patterns and castings. In order to define what may be considered a reasonable degree of accuracy in body-thickness measurements of these fittings, the following inspection limits shall be allowed:

Body-thickness measurements taken on any fitting at points diametrically opposite shall, when added together and divided by two, equal or exceed the minimum metal thicknesses given in these standards. Body thicknesses at no point shall be more than 10 per cent below the minimum metal thicknesses given in these standards.

The minimum wall thickness of each outlet of reduced fittings shall be that given in Tables 2 and 5. Any changes of thickness necessary shall be made gradually.

9 *Reducing Fittings.* Fittings may be reduced by bushing in the sand any of the outlets one size smaller, but in reducing fittings the total reduction of any outlet shall not be greater than 50 per cent of the nominal diameter of the largest opening.

Reducing tees and crosses for 150 lb. pressure on sizes from 2 1/2 to 6 in., inclusive, shall have center-to-end dimensions as shown in Tables 3 and 4. Reducing sizes for 8-in. fittings have the same center-to-end dimensions as the straight sizes.

10 *Bosses, Ribs, and Lugs.* Tapping through the bodies shall be permitted only for drain or test purposes, in which case fittings must be provided with bosses for tapping when required and when the location and size of tapping are specified. Slip bosses having

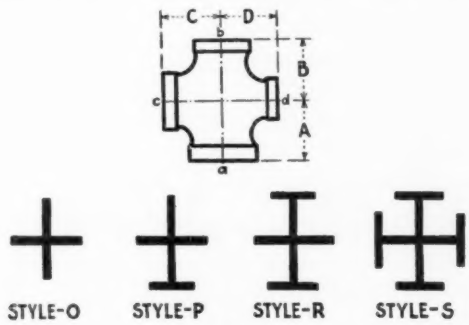

FIG. 3

TABLE 4 DIMENSIONS OF CAST-IRON REDUCING CROSSES FOR A MAXIMUM HYDRAULIC WORKING PRESSURE OF 150 LB. PER SQ. IN.

(See Fig. 3. All dimensions given in inches.)

Nominal pipe sizes a × b × c × d	Center to end A	B	C	D	Styles recommended for stock
3 × 3 × 2 1/2 × 2 1/2	4 9/16	4 9/16	4 13/16	4 13/16	P
3 1/2 × 3 1/2 × 3 1/2 × 3 1/2	5 3/4	5 3/4	5 3/4	5 1/8	P
3 1/2 × 3 1/2 × 3 × 3	5	5	5 1/4	5 1/4	P
3 1/2 × 3 1/2 × 3 × 2 1/2	5	5	5 1/4	5 1/4	P
3 1/2 × 3 1/2 × 2 1/2 × 2 1/2	4 11/16	4 11/16	5 1/8	5 1/8	P
*3 1/2 × 2 1/2 × 2 1/2 × 2 1/2	4 11/16	4 11/16	5 1/8	5 1/8	P
4 × 4 × 3 1/2 × 3 1/2	5 13/16	5 13/16	6	6	P
4 × 4 × 3 1/2 × 3	5 13/16	5 13/16	6	5 1/2	P
4 × 4 × 3 1/2 × 2 1/2	5 13/16	5 13/16	6	5 3/8	P
5 × 5 × 5 × 3	7 1/2	7 1/2	7 1/2	6 1/16	P

* This fitting may be made by bushing in the sand the size listed immediately above.

[1] See Standards Pamphlet B 1a—1924 "American Standard Screw Threads," published by THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 29 West 39th Street, New York, N. Y.

blind holes shall be provided when required to act as sockets for support (see Fig. 4).

Fittings for sizes from $2^1/_2$ to 6 in., inclusive, may be tapped $^1/_2$

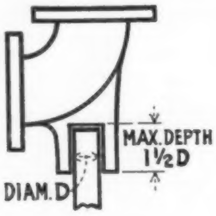

FIG. 4

in. on the side without a boss, and fittings larger than 6 in. may be tapped $^3/_4$ in. without a boss.

The addition of ribs or lugs is not prohibited on any screwed fitting.

11 *Threading.* Screwed fittings shall be threaded according to the American Standard for Pipe Thread (see A.E.S.C., B 2–1919 and the 1924 Report of the National Screw Thread Commission).

It is recommended that all internal threads be countersunk a distance equal to one-half the pitch of the thread and at an angle of 45 deg. with the axis of the thread.

The length of the threads specified in Tables 2 and 5 shall be measured to include the countersink.

12 *Fitting Dimensions.* Screwed, flanged, and combination screwed and flanged fittings for 150- and 250-lb. pressures shall have dimensions as shown in Tables 2 and 5, respectively. The 8-in. fittings are the regular American Standard flanged fittings.

In describing tees and crosses, the run is first named and then the outlet or outlets.

Due to the unavoidable variations in the making of patterns and castings and in order to establish a reasonable degree of accuracy in the "center-to-end" dimensions of all screwed fittings, the following inspection limits shall be allowed.

Nominal pipe size, in.	Center to end ±, in.	Nominal pipe size, in.	Center to end ±, in.
2	0.08	4	0.12
$2^1/_2$	0.10	5	0.12
3	0.10	6	0.14
$3^1/_2$	0.10	8	(a)

(a) See Par. 2 above.

Correspondence

CONTRIBUTIONS to the Correspondence Department of Mechanical Engineering are solicited. Contributions particularly welcomed are discussions of papers published in this journal, brief articles of current interest to mechanical engineers, or comments from members of The American Society of Mechanical Engineers on its activities or policies in Research and Standardization.

The Burden Water Wheel

TO THE EDITOR:

The descriptive sketch of the Burden water wheel on page 182 of the February issue of MECHANICAL ENGINEERING, in connection with the fine photo reproduction on the cover, seems to almost compel a note of correction and also to invite a little, perhaps supererogatory, comment.

The Burden wheel had no central shaft. There was a heavy cast-iron hub on each side integral with its journal. The internal faces of these hubs were connected across the interior of the wheel by six stiff bars, clearly seen on looking into the middle of the wheel. Power was taken from teeth on the periphery of the wheel, clearly seen in the right foreground, these teeth driving a spur pinion on a shaft which carried near its other end the flywheel in the left background, so that there was at once required some speed reduction instead of the usual heavy speeding-up gearing required by a central shaft. The working height of the water supply was some fifteen feet above the top of the wheel, which gave a valuable Pelton-wheel effect, especially serviceable in starting the rotation.

The novel ingenuities combined in this wheel were "too numerous to mention," and they alone were sufficient to show the greatness of the inventor. This wheel, by the way, showed the real designer and constructor of the noted Ferris wheel how to do it. He was named Gronau, a fellow-student at the Rensselaer Polytechnic Institute with Ferris, who was only a promoter.

Plainfield, N. J.

FRANK RICHARDS.[1]

Concerning the De Havilland Differential Aileron

TO THE EDITOR:

Our attention has been drawn to the letter from Mr. Joseph Blondin appearing in your issue of December last. May we therefore explain that we first became aware of Mr. Blondin's invention when, our patent having been accepted in England, we sought to obtain protection also in the United States and this patent was cited against us.

On investigation we readily agreed that Mr. Blondin had covered differential action of the ailerons, although his method and object in obtaining this action were entirely different from ours, and incidentally we were of the opinion that in practice his system would prove of little practical advantage.

It will be observed that the big feature in our mechanism is the fact that the last portion of the travel of the control column causes the downturned aileron to reverse its movement, the energy stored in it being then used to assist the pilot in turning the opposite aileron up to very large angles, which would otherwise be unattainable. By this particular method good control is obtained under stalled conditions and also light operation over the whole range. However, as it was apparently impossible to obtain the broad protection which we desired, we abandoned our application, despite the fact that our system had been successfully demonstrated as possessing the features claimed for it, and, so far as we know, no other machine had been built in any part of the world which by differential action gave aileron control at low speeds, which is the particular advantage of this system.

Although, therefore, in view of the facts, we cannot perhaps claim to be the first inventors of differential aileron movement, we do contend that we were the first successfully to employ a method of construction which made such differential movement possible, and the fact that our method of operation possesses such merit that it is now being used not only on all the aircraft, civil and military, which we produce ourselves, but also on a large proportion of the airplanes in the British Royal Air Force, as well as in numerous other countries throughout the world, is, we consider, sufficient to justify us in claiming at least a share in the honor of being the inventors of successful differential aileron control.

Stag Lane Aerodrome,
Edgware, Middlesex, England.

THE DE HAVILLAND AIRCRAFT CO., LTD.
By W. E. NIXON, *Secretary.*

[1] Mem. A.S.M.E.

Engineering and Industrial Standardization

The Safety Problem in Industry[1]

BECAUSE the industrial safety problem is essentially a matter of dollars and cents, many an employer has been inveigled into taking an interest in its solution to save the compensation imposed upon him by law. Employers and others have wrangled among themselves for years as to whether the approach should be from the economic standpoint or the natural assumption by the employer that the stopping of accidents is his humanitarian duty. There is no doubt in my opinion that the problem involves both factors. The altruistically minded employer satisfies his conscience and incidentally fattens his pocketbook and the economist sees the difference in the bank balance at the end of the year, and if he will look closely he will notice fewer maimed and missing persons among his workers than formerly.

The safety problem in industry is to reach 196,000 employers in the United States with the message that accident prevention will bring a larger return in money saved, greater soul satisfaction, and more real public service rendered than any other element of his business. But, if the assets are obtainable through constructive safety activities, why are so few employers giving genuine attention to the accident problem? Here are some of the explanations:

1 Employers say they are in business to make money and that even in the most hazardous trades, such as the oil industry, coal mining, steel erection, construction, and others, the direct costs of accident do not involve more than one to six per cent of the gross amount of the business done. The owner or manager says that the majority of accidents are due to foolish practices and altogether too much of his time and effort and money are required to make an appreciable saving in this six per cent of his gross income and he devotes his energy to the ninety-four per cent problem of his business. Then the majority of employers transfer their accident problem to the insurance companies by getting rid of the responsibility through the insurance premium. This type of manager does not know that the compensation costs are only about one-sixth of the real cost of accidents. He still maintains that these economies and efficiencies are only with difficulty obtained and involve refinements and altitudes in the business process that he may never achieve.

2 The second obstacle to be overcome is to convince the majority of the industrialists that every accident has a cause and that when the cause is ascertained it is relatively simple to eliminate the cause of similar accidents in the future. Unless these causes are studied, the impression prevails that practically all of the accidents are due to the carelessness of the worker; that human habits are difficult to change and that money spent on an accident-prevention program is largely a wasted effort. The employer feels that no two accidents are alike and it requires years of effort to establish new conditions and habits in the industry leading to the elimination of accidents.

3 The third difficulty is to convince employers that a vigorous accident-prevention program involves taking the worker into his confidence and assuming together the task of elimination. These educational processes lead to democratic methods of doing business and to the inexperienced seem to give to the employee rights and prerogatives that will lead to disastrous relationship. But these employers do not know that the solution of the accident problem is one that relates entirely to the preservation of human life; that it is a non-controversial problem, and where there has been liberality in the assumption of mutual responsibility by both employer and employee, the assets in better understanding and respect between employer and employee are worth more than the effort put into the safety program.

4 The fourth difficult problem is to convince the employer or manager that safety education means every individual in the industry and not the worker alone. There must be definite responsibility for the conduct of the safety program, but the safety director and his staff are the only media through whom the process of teaching is conducted. Until every individual in the industry, from president to office boy, realizes the implications of the law of self-protection and responsibility, maximum results will never be achieved. No-accident records are achieved when every individual on the property is convinced that safety is his own personal business and he must control his own action to preserve his life and limbs.

There are many other problems of a deeper character that must be accepted by the average employer before his full duty has been performed. Among these problems is the accepting of responsibility by the industry for interesting the public as a whole in the accident problem, so that when the employee goes to and from his work he will be under the protection of institutions accepting the safety principle. This involves getting behind the program for teaching safety in the schools, in the homes, to immigrants, and through our various educational institutions. The problem of safety touches every habit, affects the attitude of every individual in his entire life's experience, it touches every act and every phase of the standards of living. When people use elevators, automobiles, airplanes, and all the other thousands of modern facilities, and day by day accept conditions that lead to the living of life faster, faster, and faster, it can be realized how difficult is the problem of accident prevention and of the industry that holds up its hands and says "Be careful; be cautious." At first glance it would seem as though any safety effort would be futile, and yet it is true that accidents are under control in industry and the accidents on

[1] By W. H. Cameron, Managing Director, National Safety Council, Chicago, Illinois.

NEW A.E.S.C. STANDARDS

The following standards were approved by the A.E.S.C. during the month of January 15–February 15, 1928:

Safety Code for the Prevention of Dust Explosions in Flour and Feed Mills. (American Standard.)

Sponsored by the U. S. Department of Agriculture and the National Fire Protection Association. See p. 248.

Safety Code for the Prevention of Dust Explosions in Terminal Grain Elevators, (American Standard.)

Sponsored by the U. S. Department of Agriculture and the National Fire Protection Association. See p. 248.

Mathematical Symbols. (American Standard.)

Published by A.S.M.E.

Round Unslotted-Head Bolts (Carriage, Step and Machine Bolts) (Tentative American Standard.)

Sponsored by the S.A.E. and the A.S.M.E. Published by A.S.M.E.

Cast-Iron Flanges and Flanged Fittings—For Maximum Working Saturated-Steam Pressure of 125 Lb. per Sq. In. (American Standard.)

Published by A.S.M.E.

Cast-Iron Flanges and Flanged Fittings—For Maximum Working Saturated-Steam Pressure of 250 Lb. per Sq. In. (American Standard.)

Published by A.S.M.E.

the streets and highways are now relatively less when the number of vehicles and the increased population are taken into account.

How, then, is this complex problem to be solved in industry? The answer is by analyzing the problem and adapting the experience of thousands of industries that have cut accidents and their costs to a minimum. The employer must first assume the entire responsibility for accidents. He builds the factory, equips it, and controls its operations. He invites the workers to operate under the conditions provided by him. He must, therefore, first make sure that every physical condition is so regulated that accidents cannot be caused under any of the conditions of the work place that he provides. The next step, and involving seventy-five per cent of the problem, is to establish methods of educating the worker as to the causes and remedies for accidents and to establish policies and practices that should prevent similar accidents.

It is now true that professional safety engineers and institutions like the governmental agencies, the insurance companies, the National Safety Council, and others, can give the employer an answer to almost any safety problem. The science of accident prevention is now well established. It is equally true that the safety organization and educational methods of thousands of industries have been crystallized into simple formulas and are obtainable for nominal considerations.

Industry must accept the dictum that life is our most precious possession; that no money compensation can pay for the loss of a life or compensate for the agony of a serious injury; that intelligent and persistent efforts must be continued to stop every accident, and public relations policies adopted to lead to the conservation of life and the protection of workers everywhere.

Dust-Explosion Hazards Covered by Codes

SAFETY codes for the prevention of dust explosions in terminal grain elevators and flour and feed mills have just been approved as "American Standards" by the American Engineering Standards Committee. The preparation of the codes was sponsored by the United States Department of Agriculture and the National Fire Protection Association, and they were formulated by a sectional committee organized under the procedure of the A.E.S.C. D. J. Price of the U. S. Bureau of Chemistry served as its chairman.

A recent census of manufacturers showed that 28,000 plants in the United States, employing over 1,300,000 persons, and with an annual production of ten billion dollars, are subject to the hazard of dust explosions. Extensive research into the causes of dust explosions by the Bureau of Chemistry of the Department of Agriculture led to a study of the problem by the National Fire Protection Association, and later to the preparation of these two safety codes.

The code for terminal grain elevators provides in part for buildings constructed of fire-resistive materials with a large percentage of window space, and with smooth interior walls free, as far as possible, from pockets or ledges which can accumulate dust; roofs and side walls of belt-conveyor galleries and side walls of cupolas above bins of light construction offering minimum resistance to explosive energy; separation of buildings by as great a distance as is practicable; dustproof equipment; automatic controls for motors; isolation of drier units; complete system of cyclone dust collectors; and equipment for removal of static dust.

The code for flour and feed mills provides in part for construction of fire-resistive material with large window area and smooth interior walls; separation of cleaning department from other departments by firewalls; roofs and side walls of belt-conveyor galleries and side walls of cupolas above bins constructed to offer minimum resistance to explosive energy; dustproof equipment; cyclone dust collectors; and permanent ground wires to remove static electricity.

Height of Automobile Bumpers

THE S.A.E. Standard for passenger-car bumpers, small motor coaches, and light delivery trucks is as follows: The horizontal center line of bumper face exclusive of fittings shall be 18 in. plus or minus $^3/_8$ in. per inch of effective face, above the ground for front bumpers and 19 in., plus or minus $^3/_8$ in. per inch effective face, above the ground for rear bumpers or fender guards. The minimum overall length of front bumpers shall be 60 in. on passenger cars having the standard 56-in. tread. The minimum dimension measured between the extreme ends of rear bumpers, or fender guards, shall be 60 in. on passenger cars having the standard 56-in. tread. The minimum vertical depth of bars for single-bar-type front and rear bumpers shall be 2 in. The bumper height shall be measured with the car supplied with the normal amount of water, oil, and gasoline, but without passengers or other load. The vertical spread of contact face shall be the distance between the upper and lower edges of the outer-bumper elements, exclusive of any additional projecting parts

It is urged that car owners check up on their bumpers to see if they are attached in accordance with the above standards. Those having bumpers installed after purchasing a car would do well to have them set according to these measurements.

A.S.M.E. Boiler Code Committee Work

THE Boiler Code Committee meets monthly for the purpose of considering communications relative to the Boiler Code. Any one desiring information as to the application of the Code is requested to communicate with the Secretary of the Committee, 29 West 39th St., New York, N. Y.

The procedure of the Committee in handling the cases is as follows: All inquiries must be in written form before they are accepted for consideration. Copies are sent by the Secretary of the Committee to all of the members of the Committee. The interpretation, in the form of a reply, is then prepared by the Committee and passed upon at a regular meeting of the Committee. This interpretation is later submitted to the Council of the Society for approval, after which it is issued to the inquirer and simultaneously published in MECHANICAL ENGINEERING.

Below are given records of the interpretations of the Committee in Cases Nos. 556 (reopened), 567, 570–575, inclusive, as formulated at the meeting of December 2, 1927, all having been approved by the Council. In accordance with established practice, names of inquirers have been omitted.

CASE NO. 556 (REOPENED)

Inquiry: Is it permissible to connect a steam generating unit, constructed in accordance with the requirements of the Code for Miniature Boilers, directly to a cast-iron-body vulcanizer by means of a close connection? It is to be noted that the entire apparatus is to be tested hydrostatically to a pressure of 600 lb. per sq. in.; that the working pressure is not to exceed 100 lb. per sq. in.; that the water level is to be maintained within the generator; and that the combination is to be operated as a closed system, without extraction of steam, which makes it

necessary that no valve come between the steam generator and the vulcanizer.

Reply: It is the opinion of the Committee that a vulcanizer so connected should not be considered as a part of the steam boiler and that the Code applies only to the steam generating unit. The combination described should not conflict with the requirements of the Code, as a stop valve between the steam generator and the vulcanizer in a closed system is not required. The opening between the generator and the vulcanizer should not exceed 2 in. nominal pipe size.

Case No. 567

Inquiry: If a furnace 38 in. or less in diameter of proper thickness for the required working pressure without staying is fitted with one or more rows of staybolts, should the ordinary rules which involve the full area supported by the staybolt and the allowable stress on the staybolt be applied in determining the diameter of the staybolt?

Reply: If staybolts are used as specified in the inquiry, the requirements in the Code for the stress allowed and the spacing of the staybolts may be disregarded.

Case No. 570

Inquiry: Is it permissible under the requirement of Par. P-293 of the Code, to use a straight through-blow valve which operates with a lever-controlled cross-sliding disk, the lever being fitted with a special bracket and locking device that permits it to be locked in open position and shows clearly by an index when the lever is in such open position? As the Code rule requires that a shut-off valve in the connection to a water column shall be either an outside-screw-and-yoke type gate valve or a stopcock, can a straight through-blow valve as above described be classified as a stopcock?

Reply: The intent of Par. P-293 was that the shut-off valve in a connection to a water column shall not only be of the through-blow type so as to prevent the accumulation of scale and sediment, but also be of such a type of construction that the operating mechanism will show by its position whether it is open or closed, and can be locked in open position. If the construction of the valve referred to is such that it will meet the two requirements, it is the opinion of the Committee that it will meet the intent of the rule in Par. P-293.

Case No. 571

Inquiry: Is it permissible under the rules of the Power Boiler Code pertaining to the construction of nozzles, to attach a 10 in. nozzle to a boiler drum by the forge welding process? Attention is called to the fact that whereas the required thickness of the drum referred to is 1.05 in., a plate thickness of $1^1/_4$ in. is being used so that the additional thickness will act as a reinforcement for the outlet.

Reply: Par. P-268 of the Code formerly called for the attachment of a nozzle to a boiler shell or drum by riveting, but it is pointed out that a recent revision of this paragraph has eliminated this specific requirement for riveting and broadened the rule so that forge welding is admissible. It is the opinion of the Committee that for the conditions specified the nozzle can be attached by forge welding, in view of the fact that the stress in the metal of the drum at the working pressure adjacent to the nozzle has been determined by test and found to be within the Code limits.

Case No. 572

Inquiry: Is it permissible to calculate the strength of the tube ligaments in forge-welded boiler drums on the basis of the minimum ultimate strength stamped on the plate, provided that this does not give a higher maximum allowable working pressure than that corresponding to the weld?

Reply: It is the opinion of the Committee that in calculating the strength of tube ligaments in drums where the shell thickness is greater than that required for the working pressure, it is only necessary to refer the calculations to the plate thickness in that portion which is pierced by the tube holes.

Case No. 573

Inquiry: Does Par. P-260 of the Code mean that the reinforcement of a shell for a manhole opening shall be so proportioned as to be equal to the net efficiency of the longitudinal seam, or shall it be equivalent to the entire net area of metal removed?

Reply: Par. P-260 requires that the reinforcement of a manhole opening shall be based upon the tensile strength of the maximum amount of shell plate removed by the opening, and the rivet holes for the reinforcement, on any longitudinal line, but it is the opinion of the Committee that the tensile strength required for the full amount of metal removed shall be computed from the formula in Par. P-180, taking no account of the effect of the efficiency of the longitudinal joint.

Case No. 574

Inquiry: Is it permissible, under the requirement of Par. M-14 of the Code, to use gage cocks in place of a glass water gage on the steam generating unit of vulcanizers operated on the closed system? Or would it be acceptable under this rule to make use of a glass water-level indicator formed of a bull's eye set into the side of the steam generator?

Reply: The requirement in Par. M-14 for a glass water gage for determining the water level is mandatory and thus gage cocks will not be acceptable in lieu thereof. It is the opinion of the Committee that a glass bull's eye which is of sufficient size to indicate whether there is a proper amount of water in the boiler, and which is properly inserted in the side of the steam generating unit, may be considered as an equivalent of a glass water gage where the steam generating unit is of such size that an ordinary type of water glass cannot be applied.

Case No. 575

Inquiry: Will a seamless steel boiler tube made from material produced by the open-hearth process and of the following chemical composition conform with the requirements of the Boiler Code

Carbon	Not over 0.05
Manganese	0.20 to 0.30
Sulphur	Not over 0.04
Phosphorus	Not over 0.02
Copper	Over 0.20
Molybdenum	Over 0.07

It is to be noted that these tubes will successfully withstand all the tests prescribed for seamless tubes in the tube specifications in the Code and that while the carbon and manganese contents are both lower than those specified for Grade A material, they are both higher than is permitted for Grade B material.

Reply: It is the opinion of the Committee that alloying elements may be permitted in seamless steel boiler tubes, in which case the limits of carbon and manganese may be reduced below those specified for Grade A material in Par. S-94*b*, provided that such tubes shall meet all of the physical tests specified for boiler tubes, and provided further that the tensile strength of the material shall in no case be less than 45,000 lb. per sq. in., which is the basis of stress used in the formula of Table P-2 of the Code.

The Conference Table

THIS Department is intended to afford individual members of the Society an opportunity to exchange experience and information with other members. It is to be understood, however, that questions which should properly be referred to a consulting engineer will not be handled in this department.

Inquiries will be welcomed at Society headquarters, where they will be referred to representatives of the various Professional Divisions of the Society for consideration. Replies are solicited from all members having experience with the questions indicated. Replies should be as brief as possible. Among those who have consented to assist in this work are the following:

ARCHIBALD BLACK, Aeronautic Division
A. L. KIMBALL, JR., Applied Mechanics Division
H. W. BROOKS, Fuels Division
R. L. DAUGHERTY, Hydraulic Division
WM. W. MACON, Iron and Steel Division
JAMES A. HALL, Machine-Shop Practice Division
CHARLES W. BEESE, Management Division
G. E. HAGEMANN, Materials Handling Division
J. L. WALSH, National Defense Division
L. H. MORRISON, Oil and Gas Power Division
W. R. ECKERT, Petroleum Division
F. M. GIBSON and W. M. KEENAN, Power Division
WINFIELD S. HUSON, Printing Industries Division
MARION B. RICHARDSON, Railroad Division
JAMES W. COX, JR., Textile Division
WM. BRAID WHITE, Wood Industries Division

Fuels

Powdered-Fuel Furnaces

F-1 Under what conditions of boiler ratings, heat release, ash fusion, etc., should one apply to powdered-fuel furnaces (*a*) solid walls, (*b*) air-cooled walls, (*c*) water, ash, or slag screens or water bottoms, and (*d*) water walls?

It is difficult to make hard-and-fast rules. Other variables affecting the situation which make judgment based on experience necessary are: (*a*) duration and rating under peak boiler conditions; (*b*) furnace proportions and shape possible to obtain; (*c*) radiant-heat-absorbing surface presented to the furnace and its location with respect to refractory surface; (*d*) methods of firing—vertical, horizontal or inclined; (*e*) type of burner; (*f*) minimum rating desired; (*g*) coal characteristics and fineness of pulverization; (*h*) minimum permissible carbon carry-over and excess air; (*i*) maintenance-cost limitations. However, one will not go far astray on the average if one does not exceed the following maxima in B.t.u. per cu. ft. of heat release in designing the furnace:

Wall construction	Ash fusion, 2100 deg. fahr. and below	Ash fusion, 2100–2400 deg. fahr.	Ash fusion, 2400 deg. fahr. and above
Solid walls	never	12,500	15,000
Air-cooled walls	12,000	15,000	17,500
Water-cooled bottoms	16,000	17,500	20,000
Water walls	17,500	22,000	30,000

While many instances considerably exceeding these figures are on record, the writer has knowledge of attempts to go higher which have cost considerable expense and lost motion in getting the plant started. (H. W. Brooks, Consulting Engineer, New York, N. Y.)

Materials Handling

Pulsation in Chain Conveyors[1]

MH-2 In slow-moving chain conveyors operating at rates as low as or even less than 1 foot per minute there is often present a decided pulsation or jerking of the chain. At times, however, operation is smooth. Can any of the readers suggest a solution of this problem or mention a possible cause of the difficulty?

(*a*) The writer has found the usual cause to be as stated by Mr. M. Nelsen in the January, 1928, issue. The following has been tried with good results:

Starting at the tail-shaft end of the conveyor, that is, at the start of its travel, and at intermediate points of the route depending on local conditions, fix small wick-feeding lubricators (of simple design) to both chain runways so that a small quantity of lubricant of not too light a body is fed on to the run (not the chain). By experiment, the proper placing of the lubricators may be determined. It will be found that few lubricators are required as the chain carries the lubricant quite a distance. (Alfred LaGreca, Draftsman, Manhattan Shop, New York, N. Y.)

(*b*) In our experience with slow-moving conveyors we have of course had this condition happen. We have found that the use of cut gears or preferably speed reducers will practically eliminate any jerky motions. The unevenness in the teeth of rough gears causes an exaggerated jerky motion in the conveyor. Another feature causing jerky motion is improper tension in conveyor-chain lines. By paying close attention to this part of the equipment a good share of the jerky motion can be eliminated. The above applies primarily in connection with short-pitch chains. On long-pitch chains, 18-in. pitch or over, we use our standard equalizing gears which are designed to equalize pulsations in conveyor chains caused by the high and low positions of chain on driving sprockets. (A. K. Spolander, Chief Engineer, Link-Belt Co., Chicago, Ill.)

Management

Maintaining Quality in Manufacture

MG-1 What can be done to improve or maintain quality by emphasizing its importance to the manufacturing personnel?

A little more than a year ago, the Fairbanks-Morse Quality Clubs were organized at the Diesel-engine factory in Beloit, Wis., the pump and railroad-car factory at Three Rivers, Mich., and the motor factory at Indianapolis. These clubs aim to promote the manufacture of quality products by forming a medium for the exchange of information and instructions issued by the management. They hold frequent meetings to impress on every executive and supervisor his responsibilities with respect to quality, to promote closer contact between the shop and the inspectors, and to discuss problems of manufacture that affect quality.

Those eligible for Quality Club memberships are the factory executives, including the manager, superintendents, and a few foremen, the chief engineer and some designing engineers and inspectors. The time-study department also is represented at

[1] This subject has been discussed in a previous issue.

the meetings. Associate members are elected from a group having jobs of lesser responsibility who have indicated a desire to belong and who have served a probationary period in order to prove the quality of their daily work. Associate members are invited to attend the monthly dinner meetings and they understand that the group which they form is looked upon to furnish the future minor executives.

Meetings are usually held once a week in the cafeteria. The chief engineer presides as chairman, since in our organization the responsibility for quality rests with the engineering department, to which the inspection department reports. The programs usually include an inspirational talk and a discussion by those present of some topic of current interest. The following are suggestive of those about which programs have been built up:

Quality as Applied to Foundry Products.
Better Handling of Finished Material.
Improvements in Design from the Standpoint of the Shop.
How Good Design Can Prevent Field Troubles.
How Each Supervisor Can Promote Quality through Developing the Responsibility of the Individual Worker.

It is difficult to estimate the good these clubs have accomplished during their short period of activity for they are helping us to build not only a quality product, but a quality organization throughout. The experiment of including associate members in our Quality Club programs has proved such a success where it was first tried that it is being extended to the other plants. The standards of the inspection department have been raised and the inspectors serve more as instructors than critics. (A. J. Lindauer, Inspection Engineer, Fairbanks, Morse & Company.)

Machine-Shop Practice

Reversing Mechanism

MS-1 A certain design calls for a reversing mechanism which will carry a maximum load of 2000 lb. in a longitudinal plane for a distance of 7 ft., reversing to starting point 24 times per minute. This mechanism will be in constant use eight hours per day. Is it considered practicable to use a lead screw $2^1/_2$ in. in diameter, 2-in. lead, traveling at a speed of 1000 r.p.m. and carrying a nut, or would a preferable arrangement be some form of hydraulic feed?

As must be apparent, this would be a very radical application of the screw and nut, because of the combination of high speed of revolution, steep pitch of thread, high pressure against the nut, and rapid reversal. It is very doubtful if this is a practical or even a workable design. If built at all the screw will certainly have to be made of high-grade alloy steel (probably nickel steel), hardened and heat treated for strength and toughness. The nut will have to be of the highest grade of bearing bronze, possibly Tobin bronze or aluminum bronze. Means will have to be provided for the constant generous lubrication of the nut, and very likely it will have to be split and means provided for closing it together to compensate for wear. The writer believes also that the thread on the screw would have to be ground. The secret of success of most high-speed mechanisms is accuracy, careful balance, and cushioning of shocks. This will apply forcibly to this proposed mechanism—the last item referring particularly to the handling of the stopping and reversal.

Before abandoning this screw mechanism as an entirely impractical one, it is suggested that the A.S.M.E. Condensed Catalogues be consulted and manufacturers of machine-shop equipment and special machinery be approached.

The writer is strongly inclined to believe that a hydraulic mechanism is much more likely to succeed in this connection. A feature of one of the Machine Shop Practice Sessions during the recent Annual Meeting of the Society was a symposium on hydraulic feeds for machine tools. This is one of the liveliest topics of discussion in machine-tool design at the present time, and bids fair to revolutionize the design and operation of production tools. The problem outlined is not very different from some of those which have been solved by hydraulic means and which were described in the above-mentioned sessions. In addition to a careful consideration of the Symposium on Hydraulic Feeds for Machine Tools (obtainable in pamphlet form from A.S.M.E.), it is again suggested that the A.S.M.E. Condensed Catalogues be consulted for manufacturers of systems for hydraulic drive and the control of machinery by hydraulic means. (Guy Hubbard, Advertising Manager, National Acme Co., Cleveland, Ohio.)

Miscellaneous

Drafting-Room Light Exposure[2]

M-5 What have been the observations of readers regarding the effect of light in the drafting room, that is, the direction of exposure of windows?

The drafting room of the writer's company was formerly located at the north end of the building, and lighted mainly by the north light and a little west light. The drawing tables were arranged along the north wall, the draftsmen facing east. The lighting conditions were very good, as far as the daylight was concerned, but the artificial lighting was not planned for the drafting department, but was made to harmonize with the general office. It became necessary, on account of lack of space in this section, to move the engineering department to another locality, and the most available location happened to be on the east side of the building, which had an east wall that was about $^9/_{10}$ glass with a pebbled surface at the lower half of the sash and clear glass at the top. The drafting tables were arranged facing south along this wall. The morning sun has been a continual source of annoyance, and the peculiar glare resulting from the sun's rays striking the pebbled glass has also caused annoyance to the draftsmen. The artificial lighting is accomplished by means of Cooper Hewitt lamps hung parallel with and near the tops of the windows, actually being about five feet above the heads of the draftsmen, and approximately four feet to the left of them. This artificial lighting works out very nicely. The location of the drafting department is again to be changed, due to further expansion, and space is being arranged in a new building similar to the space occupied at first; that is, with north light, with the draftsmen facing east, and the west end of the drafting room having a little west light. On account of the uniform conditions obtained in this manner, it is considered superior to any other arrangement. (A. G. Sutcliffe, Chief Engineer, Ilg Electric Ventilating Co., Chicago, Ill.)

Questions to Which Answers Are Solicited

Stoker Operating Costs

F-2 How much in cents per ton should average stoker maintenance run for (*a*) underfeeds, (*b*) chain grates. Please state what part of figures given are for material and parts, and portion allotted to labor of installation. Also, state length of period over which the figures given have been averaged and how recently they were compiled.

Troubles with High Boiler Pressures

R-3 What trouble has so far been experienced with high boiler pressures on locomotives?

[2] This subject has been discussed in a previous issue.

MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

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BY-LAW: The Society shall not be responsible for statements or opinions advanced in papers or.... printed in its publications (B2, Par. 3).

Fundamentals and Adaptability

AN ENGINEER who has shown himself particularly adaptable has made the complaint that his academic education was deficient in its training for that very quality. He was, he says, filled with the details of steam engineering in an age which was turning more and more generally to the use of electricity, and given little or no instruction in the fundamentals of internal-combustion motors to guide him in adjusting his point of view to the introduction of the Diesel engine. He has complained also of a lack of breadth of vision on the part of his instructors, whose academic orthodoxy was so strict as to admit of no question of authority and no innovations in method or curriculum.

There are some who must by their nature question the eternal verities—"pickers-up of learning's crumbs, the not incurious of God's handiwork," who are the disciples of truth and who rail at dogma. Such men are admittedly thorns in the flesh of the incompetent or uninspired teacher who fails to recognize in them anything but a disturbing element in the classroom, lacking the intellectual docility of the rest of the flock. Such men naturally resent the lack of sympathy with which their youthful enthusiasm and inquisitiveness is met and the attempt to warp their more virile mentalities into the pattern of the mediocre average. Waste in educational process exists here, but perhaps not permanent harm, inasmuch as these militant intellects usually thrive on opposition and subsequently have the satisfaction of vindication.

The more serious problem is training the adaptability of the average student so thoroughly in fundamentals that no sudden shift in the day's dogma will leave him bemused and tottering in the mists of confused understanding, but will give him that eager expectancy which forecasts tendencies in the technical world, and that basis for judgment which evaluates them correctly when they become actualities. Educators, as a rule, recognize this. They know that their textbooks suffer from a rapid obsolescence, and most of them have seen a number of radical changes in the span of their own careers. They also recognize in their students an almost universal lack of perspective and a misplaced emphasis on what is important. Continual repetition of irksome fundamentals which even the most veteran scientist still may understand imperfectly, seems like a waste of time to the novitiate who conquers with the glib and parrot-like recitation of a definition the perplexities of essential theories. Give him a formula and he will supply a correct solution, teach him an approved laboratory technique and he will produce consistent results; but ask him to apply the principles upon which the formula was based to the derivation of a slightly different relation, or ask him to revise his technique to apply to an original investigation, and the man will usually exhibit an ignorance of the fundamentals and a lack of adaptability that is the despair of his instructors.

Much of this ignorance and lack of adaptability is due, we suspect, to the inherent qualities of human nature, but there exists, none the less, a challenge and a responsibility to the educator that he shall keep in mind the fact that he is teaching men who enter a profession which is in a state of constant and rapid advance, and that the value of the training will be largely lost unless he can imbue his students with a clear sense of the importance of fundamentals and unless he can train them to be easily adaptable to the changes they are sure to face.

Baccalaureate Degrees

THERE undoubtedly existed in the minds of the faculties of engineering schools a very substantial reason for departing from the familiar forms of baccalaureate degrees and granting to graduates from their courses such practical and intelligible designations as civil and mechanical engineers.

A degree of this kind, however, suffers from two inherent defects: first, it is the name of a profession, and, second, it is not exclusively a baccalaureate degree. There is no reason why a man practicing the profession of mechanical engineer should not so designate himself; in fact, an examination of the Year Book of the A.S.M.E. will reveal the initials M.E. after the names of many members of the Society, indicating not that they have completed a course of study at an engineering college and have received this degree as evidence of their success, although many of them have, but that they occupy a position bearing this title. The ambiguity which exists here can be eliminated by giving up the degree in this form and substituting for it something more typically academic.

The second objection to the degree is the result of practices entirely within academic circles—a lack of uniformity in meaning and procedure. The degree has the variety of meanings, in the various schools of the country, which ordinarily attach to the baccalaureate, master's, and doctorate degrees in other departments of a university. It is given by some colleges for undergraduate study, in others for graduate study in residence, in others as recognition of professional attainment entirely outside of college curriculums, and in still others for combinations of all of these. Surely there is no uniformity of training or of attainment recognized by the universities indulging in these divergent practices.

With this confusion as it now exists, it is gratifying to note the occasional change in policy of an engineering school which substitutes the baccalaureate degree for the indefinite M.E. or C.E. at the end of the usual course of undergraduate study. It is hoped that all engineering colleges will speedily adopt this policy.

Munitions Preparedness Impossible Without Adequate Personnel

THE Army of the United States is, as it should be, a skeleton organization and a training nucleus. The United States does not need a large permanent military establishment. We are at peace and our frontiers are safe. We desire to remain at peace and we believe that the best insurance for peace is an adequate plan for preparedness which takes into account the tremendous industrial effort that a military emergency entails. Our last war has been termed as an engineers' war because applied technology was employed so extensively in waging it and in producing the materials for it. As engineers we are a part of the comprehensive plan for National Defense, and as citizens we are vitally interested in the preventive effect of a complete plan thoroughly carried out.

Lives are tossed away, materials and money are spent prodigally and to no avail if an army in the field is not bountifully supplied with modern weapons and ammunition. This seems axiomatic, yet as a nation we have been obliged to relearn the lesson during each one of our major conflicts. The last war made a more lasting impression, as evidenced in the National Defense Act of 1920 which provided an Assistant Secretary of War whose sole function is to insure plans for mobilizing industry in support of the army. This Act and the efforts of the men who have occupied the new office have borne fruit. Many facts never before known have now been determined. Definite quantities have been established for the important items of material needed in a major military effort. Something is known about the factory capacity and equipment necessary to supply these items, and the new plants needed have been estimated. Many other critical requirements have been provided for, but one major factor seems to be in doubt, namely, that concerning the necessary skill which comes from experience in the actual manufacture of military material. At present we have this skill in those who labored to produce war material in 1917 and 1918. It should not be lost to those future generations which may be called to arms in a major emergency. Military material is not an ordinary product of industry. Special skill of a high order is required in its manufacture, particularly in ordnance, without which an army would be little better than a political marching club. "Educational orders" for small quantities placed in factories where emergency plans had been worked out should be of great assistance. But before educational orders can be placed on a scale large enough to really train industry many preliminary steps must be taken. Many parallel activities must also be directed. These require personnel, more personnel than is apparently available.

In December, 1926, a report of the National Association of Manufacturers pointed out that 1700 regular officers are revealing the mysteries of "squads right" to civilians of the National Guard, Organized Reserves, and Reserve Officers' Training Corps, while only 24 officers are teaching industry some of the intricacies of making highly technical military material. Industry has offered full cooperation. Reserve officers assigned to industrial mobilization, including many who struggled against odds in our latest, and we hope our last, emergency are giving freely of their time and effort to help avoid a similar period of hasty and uneconomical preparation. Industry and these reserve officers, no matter how great their enthusiasm, can devote but a small part of their time to the work in hand. They need help in the shape of Regular Army ordnance officers technically trained to whip an emergency plan into shape in each factory. The need for this assistance is immediate.

In the autumn of 1927, Hon. Hanford MacNider, then Assistant Secretary of War, recommended that the Ordnance Department be increased by 60 officers for this purpose. Some definite steps for the more remote future have also been taken. Just before resigning as Assistant Secretary, Colonel MacNider proposed a Munitions Battalion to be made up of college students who, having completed courses in the elements of military science, shall devote a portion of their time to a study of basic procurement problems. This has been recommended to Congress for legislation.

These recommendations for more Regular-Army officers on production and for the establishment of a Munitions Battalion have been endorsed by the A.S.M.E. National Defense Division Executive Committee and by the Council of the Society, and they have been forwarded to the American Engineering Council which will act on them in March. As our distinguished Past-President, Mr. Charles M. Schwab, stated at West Point on May 12, 1927, in his address to the United States corps of cadets: "What we need is a completely balanced program for national defense, with the Army paying proper attention to munition power as well as man power. Rifles without men to use them would be a needless waste of money, but men without rifles would involve a ghastly sacrifice of thousands of brave young lives. As conditions are today, our program of national defense is critically out of balance. We look to you military leaders of tomorrow to give your thought, and bend your energies to the solution of the ordnance problem—the crux of national defense."

Large Plants and Small

IN THESE days when the capacities of power-generating units reach up into the hundreds of thousands of kilowatts, when billion-dollar corporations are becoming quite common, and when production is apparently carried on in stupendous units—automobiles, for example, at the rate of millions a year—it comes somewhat as a shock to be told by the National Industrial Conference Board that even in the great industrial states of the country the average number of wage earners per plant is well below one hundred. Here are the figures, the grand average of which is 50 workers per plant.

State	Number of plants	Number of wage earners	Average number of wage earners per plant
New York	33,393	1,066,202	32
Illinois	14,117	622,368	44
New Jersey	8,204	425,377	52
Pennsylvania	17,298	999,460	58
Massachusetts	10,027	591,438	59
Ohio	11,137	676,742	61
Connecticut	3,062	242,362	79
Michigan	5,600	515,494	92

It would require a very elaborate investigation to determine completely the true meaning of these figures. For example, in New York State the preponderance of small factories, the Conference Board finds, is due to a large extent to conditions peculiar to New York City where such industries prevail as require little space and depend for their profit on a "high value added by manufacture" rather than on volume: namely, the clothing, millinery, lace goods, and jewelry industries and the like. But in Massachusetts, Connecticut, and Michigan, where these conditions do not form a controlling factor, the average number of wage earners per plant is still quite low. It should be remembered in this connection that these are average numbers of wage earners, and that all establishments reporting a production value of less than $5000 during the census year, and all the smaller custom establishments, such as custom tailoring, dressmaking, etc. are eliminated. Since in all of these states there are very large plants employing from 5000 persons

up, there must be a tremendous number of very small concerns way below the average to bring the latter down to such a low figure. It should also be remembered that the bulk of our production comes from the large plant.

What does this very small plant do and how does it make its living in the face of the competition of the big plant? There are not sufficient data to give a complete and reliable reply on this question. The following may, however, suggest the character of the general answer: In the first place, a good many of these small plants are of a purely local character and are not in competition with large plants. A local garage or machine shop competes only with similar establishments in its neighborhood, and the character of the neighborhood quickly sets a limit to the largest size of the establishment possible there.

In the second place, the small establishment may be employed in manufacturing specialties which do not have a market large enough to warrant their manufacture by the biggest plants, and on which the character of the work is of such a nature as to require more individual supervision than can be given in the large shop.

The third class of small establishments makes its way because of cheapness of production, and this cheapness is due to the fact that the owner and sometimes members of his family are employed in working or managerial capacities in the little plant and can afford to work for wages only without a profit. This may not be a sound economic policy, but it gives them a modest competence, with which they are satisfied, and provides enough incentive to keep the plant going.

It may also be found that much of the overhead of a small shop, in the way of plant, equipment, and personnel, constitutes a smaller percentage of its manufacturing cost than is the case with its larger competitor or than will be the case when it undergoes the complications of growth; and there is further the tendency of some small establishments to operate at a loss with the idea of breaking into or maintaining a position in a market, conditions which may explain the existence of many small manufacturing concerns.

While the figures quoted do not reveal the fact, it would appear from other sources that there is a general tendency toward a concentration of very small plants at one end of the scale and very large ones at the other, the medium-sized plants being gradually squeezed out of existence between the cheap price and individuality of the small plants on the one hand, and the high efficiency and superior organization of the very large plants on the other.

The present numerous mergers bear witness to this tendency. Had the general economic condition of the country been unsatisfactory, there would have been failures of these medium-sized plants in large numbers. As, however, many plants accumulated substantial reserve funds during the war years and had a record volume of business for several years subsequent thereto, the general tendency is not so much for the plant that finds it difficult to keep its place in the sun to go out of business as it is for several such plants to combine into a little "octopus" of their own. Thus, facing the competition of the continuous sheet mill, six midwestern sheet-steel manufacturers have combined into quite a sizable unit. A group of gear and forging manufacturers have done the same. The Youngstown Sheet and Tube Co. is discussing a merger with the Inland Steel Co., while the United Alloy Steel Co. and the Central Alloy Steel Co. have put a merger through, and the Republic Iron and Steel Co. has practically merged with the Trumbull Steel Co. In the engineering and construction field a consolidation has been formed combining the Dwight P. Robinson & Co., Inc., the U. G. I. Contracting Co., Day & Zimmerman, and the Public Service Production Co. And to top this movement, the Texas Co. has announced its consolidation with the California Petroleum Co., the capital of the emergent concern being in excess of half a billion dollars.

Only the future will show whether such movement is really sound. This country is quite big enough to provide business for many more concerns with a total investment running into hundreds of millions of dollars, but there are indications that it is easier to find the money for these huge combinations than the managerial talent to run them. When Judge Gary died, several months elapsed before a satisfactory way of replacing him was devised, and even then the work which he had done alone was divided among three men, and a man as busy with matters of the highest importance as J. P. Morgan had to be drawn into the triumvirate.

To all practical purposes it would appear that the financial and engineering methods of handling the big corporations have been already sufficiently perfected; the human-engineering element, however, still remains to be developed, and until it has been there will be a weak link in a highly stressed part of these large structures. This weakness is probably not enough to cause a collapse of the structure, except under very unfavorable circumstances, but it may lead to leaks, and leaks cost money when business is done on a scale of hundreds of millions of dollars.

What the Young Railway M.E. Should Read, and Why

THE progress of a college-trained mechanical engineer in railway work has been a subject about which a great deal of study has been centered and a great deal of discussion engendered. The reason for the small number of this group being engaged in railway service seems to be rather obscure. Has his education been such as to properly fit him for succeeding in this highly competitive, widely diversified, energy-consuming field? Has it been broadening enough, and has it been sufficiently thorough in its treatment of commercial subjects?

The tendency of the mechanical engineer's education has been to narrow his viewpoint and to concentrate his attention upon points rather than upon broad principles. This is primarily due to the intensive study of the mathematical and of the applied-science subjects, with their inelastic and rigorous limitations. He is trained to remember, always, that two plus two make four, and never anything else.

If he is to succeed and progress in his chosen field, he will have to contend with the human element. After dealing with human beings for a while, one finds a new respect for the rigorous and unyielding rules of mathematical operations. However, much as one regrets their lack of adherence to fixed rules, one has to deal with many human beings, and it is therefore very necessary that the mechanical engineer endeavor to so equip himself that he can direct their energies with the greatest practicable efficiency.

Untrained observation of them will not suffice. It is too slow a method. He must read publications of many different fields if he is to acquire that breadth of view and that tolerance of thought which must be had if he is to intelligently and effectively direct human beings. He must read good newspapers thoughtfully, the better of the popular novels, and endeavor to become familiar with the elementary factors in music, art, religion, international history, and national and international politics.

But, above all, he should read and study, intently, books on commercial geography, economics, and banking and finance. A comprehension of the field treated of by these subjects will enable him to understand that which is so frequently misunderstood: the real reason for a railway's inception and existence, according to our present social system. A railway is a business

machine, and its primary purpose is to earn money for its owners. A huge bridge is not constructed, or a beautiful locomotive fabricated, simply to broadcast the ability of the civil or the mechanical engineer, or to satisfy the pride of the railroad's president. Money is spent for them simply because it is believed their construction and use will produce materially more than they cost. Strange as it may seem, this fundamental fact is too often overlooked in the early years of our professional life.

Our college-bred engineers are splendidly trained, both with respect to the breadth of the technical side of their work and to thoroughness as well, but too few of them, I regret to say, have anything like a proper comprehension of what commercial ventures have forever before them, that is, the production of a healthy net-income item.

If the mechanical engineer in railway work is to be as successful as he should be, he should also be able to think clearly and logically, and speak with force and clearness in public. This does not mean, especially, training in oratorical forms; it merely means that one should be taught to think easily and to speak with confidence before public gatherings.

H. N. Rodenbaugh.[1]

A.S.M.E. Research Accomplishments

ENTERPRISES both industrial and engineering are judged these days by their practical concrete accomplishments. In applying this test to A.S.M.E. research activity we shall not find it wanting.

In the brief eighteen years of its existence the standing committee responsible for the Society's expression in the field of research, the main Research Committee, has accumulated the kind of experience which enables it to produce real contributions to the knowledge of mechanical engineering. These contributions are, of course, the results of the experimental work carried on under the auspices of the A.S.M.E. Special and Joint Research Committees and financed by the related industries.

Notable examples of these projects are the studies now in progress on elevator safeties, strength of gear teeth, properties of steam, boiler feedwater, boiler-furnace refractories, mechanical springs, effect of temperature on the properties of metals, fluid meters, and welding of pressure vessels. The progress reports which are published from time to time by the committees conducting these studies constitute valuable contributions to the literature of their respective subjects. Not the least of these publications are the bibliographies which result from the committees' studies of the literature of their subjects. In the last seven years these Research Committees have issued seventy-five reports and publications of various kinds.

It will be appropriate here to note the results of the investigational work of its committees to which the Society can point with considerable satisfaction. Probably the best-known work has been done by the Steam Tables Committee which, through extensive research, has collected a large amount of accurate data on the physical constants of steam over the entire range of usable pressures probable in the future. These determinations have been used in revising existing steam tables, and applied to the design of steam-using equipment to meet present-day needs. The study of alloys has been greatly aided by the Bearing Metals Committee through its development of an instrument known as the "Microcharacter" by which the hardness of individual crystals of an alloy can be measured. Mention of bearing metals brings to mind the subject of lubrication to which a research committee of the Society has contributed much new and valuable information on viscosity of lubricants at high pressures, oiliness, and friction in journal bearings. In still another field the Boiler Furnace Refractories Committee has collected, analyzed, and published a large amount of data on the factors governing the failure of refractories in various types of boiler-furnace installations. Of great importance and usefulness also is the report of the Fluid Meters Committee on the theory and application of various existing types of fluid meters, a publication that is generally considered a standard reference book on this subject.

To carry forward the twenty-four projects which have received authorization by the Council, the Main Research Committee has enlisted the services of two hundred and ninety of the Society's members and others. These committees are following or supervising the work of seventy men who are spending full or part time in actual research. Investigations are in progress at five Government laboratories, eight university laboratories, twenty industrial laboratories, and by four separate field groups.

Truly such a forward-looking enterprise should receive the enthusiastic endorsement of every A.S.M.E. member.

Fire-Hose Couplings Aid Fire Fighting

THE great advantages derived from the use of nationally standardized fire-fighting equipment were recently demonstrated in a complete way during the conflagration at Fall River, Mass., on February 2 and 3.

The fire was first discovered in the engine room of the Pocasset Manufacturing Company and was said to have originated from a steel barrel which was being used as a stove by the employees engaged in razing the building. The fire having ignited the floors and partitions, spread rapidly through the mill and was soon beyond the control of the local fire department. Emergency alarms were sent out, and fire departments of nearby cities and towns quickly responded. Twenty city blocks were burned, however, before the spread of the flames could be checked by the diligent work of twenty-nine companies with their equipment from eighteen cities. Damages are estimated at $12,500,000.

Fall River was not among the first of the New England cities to recognize the advantages to be derived from the national standardization of the threads on fire-hose couplings, but three years ago, in 1924, the city adopted the National (American) Standard and adjusted all fire-fighting equipment to comply with it. Seventeen of the eighteen cities which responded to its call last month had also changed their equipment to agree with the National (American) Specifications, so that no difficulty was experienced in attaching their apparatus quickly and effectively where needed. The apparatus from but one city was found to be non-standard and was kept out of service until the necessary adapters had been secured.

Few communities are equipped with fire-fighting forces and equipment sufficient to handle more than the ordinary fire. As soon as a fire has gained headway beyond these limits its spread becomes uncontrollable and must be left to burn itself out, unless effective outside assistance is speedily secured. Realizing this, many organizations have taken part in the attempt to establish in the United States complete interchangeability of fire-hose-coupling threads. The National Association of Fire Engineers began the campaign in 1875 with the adoption of a proposed standard. This was revised in 1891. With the stimulus of the Baltimore fire in 1904 the National Fire Protection Association, the Bureau of Standards, the American Water Works Association and The American Society of Mechanical

[1] Vice-President in Charge of Operation, Traffic and Construction, Florida East Coast Railway Co., St. Augustine, Fla. Mem. A.S.M.E.

Engineers took an active interest in the furthering of this desirable project. In 1925 the American Engineering Standards Committee approved as an American Standard a complete set of product gage dimensions.

The National Board of Fire Underwriters in 1920 undertook the task of promulgating this standard, and up to the end of the calendar year 1926 a total of 2238 protected cities and towns had adopted the National (American) Standard, having resized their equipment and arranged for the careful gaging of all new equipment. As a result of this activity approximately 40 per cent of the total number of protected cities and towns in the United States have adopted and put into use the National (American) Standard. Twenty-five of the cities included in this group have a population of more than 100,000. At the present time in twenty-four states the conversion process is now well organized and progressing satisfactorily. It behooves every member of the Society to make inquiries of his home-town authorities to ascertain their attitude toward the standardization of fire-hose couplings.

Photography—An Engineering Tool of Great Value

IT HAS been characteristic of the human race since the beginning of history that conditions and surroundings of the moment are not good enough—there must always be attempts to peer into the future, or new and strange lands must be explored. Now, it is a well-known fact that the extent to which one is able to explore an unknown region depends upon the value of one's equipment for penetrating that which obscures the view. A recently discovered tool of great value to the engineer-explorer is photography, as is shown emphatically in four papers appearing in this issue. To the explorer of metal structures, for instance, photography, with the newly developed methods of using the ultra-violet ray and the perfection of high-magnification apparatus have increased greatly the field of vision and have given him a picture of crystal formation of inestimable value in the production of new alloys. It is even possible to study the atomic structures of metals with the aid of the X-ray, and measurements of the order of millionths of an inch are not uncommon. With the knowledge thus gained, it is not difficult to understand the action of certain metals when attempts are made to combine them, and methods of procedure to produce the desired results by adding other combinations of atoms are suggested.

The value of photography as an engineering tool is not confined to the investigation of metals by any means. There are innumerable phenomena which occur at speeds too great to be observed by the unaided eye, and there are other phenomena which require speeding up to permit proper investigation. Notable among the former is the problem of oil-engine sprays, the manner in which they fill the combustion chambers and the effect their action may have on the combustion of the fuel and the transfer of the released energy into effective power. High-speed motion-picture photography has made it possible to watch the growth of the spray and subsequent events within the chamber, and has furnished the data necessary to enable the engineer to design the equipment best suited to the requirements of high-speed operation. Explosives have been studied to advantage by this method, and valuable information on the explosion of airplanes in crashes has been gained by photographing an actual crash. The point at which the explosion starts and the direct cause is readily apparent as the action is slowed down by the slow-motion projector. Ultra-high-speed photography has been applied very successfully to the study of airplane propellers and wings. The flow of the air about the thrashing blades is accurately portrayed, and the effects of various wing structures on the air stream can be observed with ease. Also, it is possible to watch a steel-jacketed bullet slowly bore its way into a piece of armor plate, or to observe the action of projectiles as they encounter the resistance of the air in their travel. Passing to the other extreme, we may now watch the growth of bacteria as it is stepped up from a slow process to one taking no more than two or three minutes. Growing plants may be observed to writhe as their growing time is condensed from days into minutes.

Graphic records of phenomena too faint for observation in any other manner are now possible through the use of a moving light ray playing up on a sensitive film or plate.

Gradually the unexplored area narrows, and with the elimination of the unknown there follow new materials of construction, a better understanding of natural phenomena, and a compilation of records the value of which it is impossible to calculate.

Concerning Certain Statements Made in the Society's Publications

ON FRIDAY, November 25, 1927, the Executive Committee of the Council of The American Society of Mechanical Engineers held a meeting to hear the statement of a member of the Society who claims he is the person referred to in the anonymous statements in certain publications of the Society, and alleges that thereby an injustice has been done him. Following are the statements, with the words italicized, to which objection is taken:

> This characteristic helpfulness to others held good to the very day of his death. For another of his "boys," Mr. Wm. C. Brown, tells me that on the morning of that day—it was the eighth of last May—a man from Texas, whom he had never heard of before, walked into the Professor's office to ask advice about a *valve motion* he had invented. When it had been explained but before Professor Sweet had an opportunity to express an opinion, his carriage came and he was obliged to go home to lunch, making an appointment for the man to return at a later hour. That afternoon the fatal stroke occurred and Professor Sweet was taken home by Mr. Brown, in the latter's car. On the way, though suffering intense pain, he told Mr. Brown about the stranger's errand and begged him to see the man when he returned and explain to him just why his *valve motion was of no value*.—Transactions, vol. 38 (1916), no. 1579, p. 1325.
>
> The last day of Professor Sweet's life was typical of all his days. Though he was eighty-three years of age, he went in the forenoon to the office of the Straight Line Engine Company. Just before noon there came to the office a man from far away, who knew Professor only through his articles in the "American Machinist," to ask advice about a *valve gear* that he had designed. They had talked for *only a few minutes* when the carriage came according to custom and carried Professor home for the noon hour, an engagement having been made for another meeting at three o'clock. After luncheon Professor returned to the office, but by two o'clock was suffering severe pain. W. C. Brown, one of Professor Sweet's "Boys," who was at the works with him, took him home in his car. On the way, despite acute suffering, his whole thought was to tell Brown, for transmission to the visitor, what he would have said if he had been able to keep the engagement. At eight o'clock he died. His anxiety was that he should not fail in helpfulness. It was a fitting close to a beautiful, unselfish life.—Biography of John Edson Sweet, by A. W. Smith, p. 18, and also Mechanical Engineering, vol. 47, March, 1925, p. 160.

It was reported to the Executive Committee that the foregoing statements are in error as to the time spent with Professor Sweet by the person mentioned. It appears that it was two or three hours instead of the short time mentioned in the printed accounts.

It was also reported to the Committee that the matter discussed between the visitor and Professor Sweet concerned an inertia governor, and not a valve gear or motion as stated in the excerpts printed above. The visitor had been sent by the

company with which he was associated to interview Professor Sweet as to the merits of this governor.

It was further reported that the printed accounts are in error in saying that Professor Sweet condemned the visitor's invention, and that the valve motion said to have been discussed was the invention of another person than the visitor.

The Executive Committee accordingly recommended that the substance of what precedes be brought to the attention of members and purchasers of the Sweet biography through the medium of the Society's publications. The action of the Executive Committee was approved by the Council of the Society, and this publication is made in accordance therewith.

U.E.S. Report for 1927

THE business of the United Engineering Society committed to it by its Founder Societies under its Charter, the Founders' Agreement, and the Library Agreement, is conducted by its Board of Trustees, consisting of three representatives from each of the four societies. This business is transacted by the trustees at their ten monthly meetings, and through the Finance Committee, the officers, the staff, and special committees.

The Engineering Societies Building is tax exempt. It is administered in the main on a cooperative basis and not for profit. Revenue from associate societies and from meeting halls reduces the burden upon the Founder Societies for maintenance, operation, and fixed charges on the building. To each Founder Society interest at the rate of 4.8 per cent per annum is paid on its investment of $262,500 in the land and building, amounting to $12,600 a year. The United Engineering Society administers also several trust funds for the Engineering Foundation and Engineering Societies Library.

These activities, therefore, are of vital interest to every member. An excellent cross-section of the work of the U.E.S. during 1927 may be gained from brief excerpts of its annual financial report as given in the accompanying summary and balance sheet.

SUMMARY OF REPORT

OPERATION OF BUILDING

Credit balance January 1, 1927		$11,694.24
Building revenue, 1927	$134,945.82	
Building expenditures, 1927	115,962.32	18,983.50
		30,677.74
Annual payment to Dep. & Renewal Fund	$ 12,000.00	
Part cost of alterations, basement and 6th floor	11,346.39	23,346.39
Credit balance December 31, 1927		$ 7,331.35

OPERATION OF LIBRARY

Maintenance revenue	$ 44,232.92	
Maintenance expenditures	44,142.92	
Credit balance Dec. 31, 1927	90.00	
Transferred from Service Bureau balance	470.14	560.14
Deficit Dec. 31, 1926		560.14
Balance Dec. 31, 1927		
Service Bureau revenue	$ 20,782.76	0.00
Service Bureau expenditures and adjustments	19,415.77	
Credit balance Dec. 31, 1927	1,366.99	
Credit balance Dec. 31, 1926	1,933.34	3300.33
Transferred to Maintenance		470.14
Net credit balance Dec. 31, 1927		$2,830.19

FUNDS AND PROPERTY

Funds held by U.E.S. Dec. 31, 1927 (book value):

Depreciation and Renewal	$ 208,058.03
General Reserve	7,500.00
Engineering Foundation	504,536.77
Henry R. Towne Engineering	49,953.13
Library Endowment	103,340.97
Reserve for Depreciation of Capital of Library	4,000.00
Edward Dean Adams	100,000.00
John Fritz Medal (U.E.S. Custodian)	3,500.00
Louvain Memorial subscriptions	12,345.48
Total	993,234.38
Real Estate owned by U.E.S., cost to Dec. 31, 1927	1,973,410.42
Operating cash and petty cash	9,785.95
Accounts receivable	3,259.74
Value of Library (as appraised for insurance)	349,739.00
Winchell Library Suspense Account	838.00
Total Property for which U.E.S. is trustee or custodian	$3,330,267.49

BALANCE SHEET

ASSETS

Real Estate

Land	$ 540,000.00	
Building	1,376,239.26	
Equipment	33,171.16	
Founders' preliminary expenses	24,000.00	$1,973,410.42

Investments and Cash Uninvested

Depreciation and Renewal Fund	208,058.03
General Reserve Fund	7,500.00
Engineering Foundation Fund	504,536.77
Henry R. Towne Engineering Fund	49,953.13
Library Endowment Fund	103,340.97
Reserve for Depreciation of Library Capital	4,000.00
Edward Dean Adams Fund	100,000.00
Louvain Memorial Fund—cash in bank	12,345.48
Operating cash and petty cash	9,785.95
Accounts receivable	3,259.74
Winchell Library Suspense Account	838.00
Total	$2,977,028.49

LIABILITIES

Founders' equity in property	$1,973,410.42
Depreciation and Renewal Fund	208,058.03
General Reserve Fund	7,500.00
Engineering Foundation Fund	504,536.77
Henry R. Towne Engineering Fund	49,953.13
Library Endowment Fund	103,340.97
Reserve for Depreciation of Library Capital	4,000.00
Edward Dean Adams Fund	100,000.00
Louvain Memorial Subscriptions	12,345.48
Louvain Expense Account (balance on hand)	381.70
Endowment Committee Expense (balance on hand)	2,494.95
Deposits on account hall rentals	306.50
Deposits Library Service Bureau	39.00
Deferred Credit—Library-Associates Contribution	500.00
Credit balance in activity accounts	10,161.54
Total	$2,977,028.49

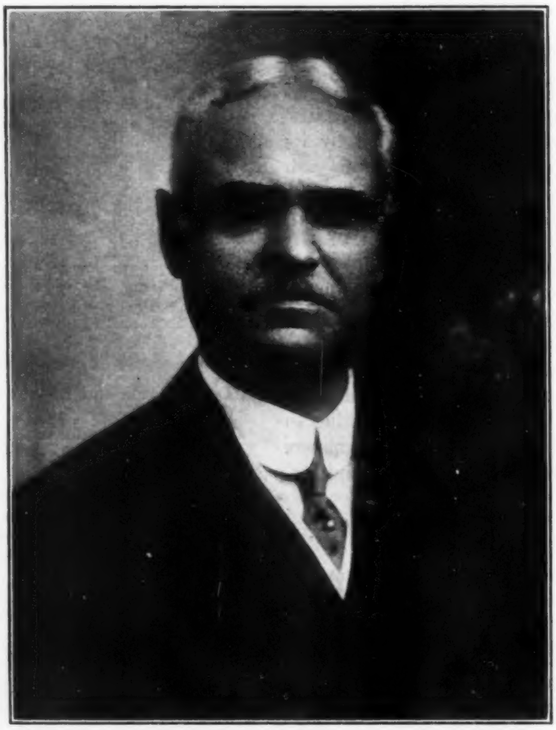
Errata

ON PAGE 70 of the January issue, in the description given of the Wilkin flexible gear-tooth system, the second word on the second line below Fig. 3 should read "contracting." We are informed by Mr. Wilkin that the system is patented and not open to public use.

We are advised by V. T. Malcolm that the ordinate values in Fig. 8 of his paper, page 141 of the February issue, should read 0.01 and 0.02 instead of 0.10 and 0.20 as they appeared on the figure.

George Washington Goethals

THE death of Major-General George Washington Goethals, on January 22, 1928, marked the close of a long and illustrious career and the passing of a great engineer and a great American. The building of the Panama Canal, in which General Goethals succeeded after many distinguished American and European engineers had failed, took seven years, and is regarded as one of the greatest engineering feats of history. Four centuries before it was completed a canal across the Isthmus of Panama had been projected by Balboa and other early Spanish explorers. On the making of this great project an accomplished fact, the fame of General Goethals rests securely.



George Washington Goethals

Born in Brooklyn, N. Y., June 29, 1858, of Dutch parents, he was educated in the public schools of his native city. He early showed such promise that the principal of the school he attended worked to get him an appointment to the military academy at West Point. The appointment came in 1877 after Goethals had been a student at the College of the City of New York for three years.

The second honor man of his class, he was graduated from West Point in 1880 and was assigned to work in the Cincinnati district to improve the channel of the Ohio River for navigation. He returned to West Point for several years as instructor in astronomy and civil engineering, but in 1889 was sent back to Cincinnati for further work on the Ohio River. There he obtained his first practical working experience in canal-lock and dam construction. Later he was placed in charge of the Muscle Shoals Canal on the Tennessee River and of another canal near Chattanooga. At the beginning of the Spanish War in 1898 he was commissioned a lieutenant-colonel of volunteers and appointed chief engineer of the Porto Rican Army of Occupation, and served throughout the war in that capacity.

After the war he returned to the regular army, and his reputation for engineering skill was so well established that, in 1907, when President Roosevelt decided to take the work of building the Panama Canal out of the hands of civilian engineers and put the responsibility upon the United States Army Corps of Engineers, Goethals was chosen to head the work.

In the face of much criticism and opposition General Goethals favored the abandonment of the sea-level plan and putting the lock plan into effect. Finally a special commission of inquiry upheld him and he proceeded with his work. He made other changes in the plan such as widening the canal that indicated his engineering genius and foresight.

But he shone as an administrator even more than as an engineer. President Roosevelt appointed him not only chief engineer but also chairman of the Canal Commission, and Goethal's greatest achievement was in the administrative function of organizing a highly efficient system for the coordination of all factors—sanitation, excavation, commissary, housing, labor, design, and construction. A man of great force and personality, he inspired complete confidence in the entire organization and brought it together in harmony. The canal job, which had been looked upon in many circles as impossible, came to be known as a model of efficient labor and industrial harmony as well as of sound engineering. So well was the work done that it was finished nearly a year ahead of the time originally contemplated.

The canal reaches from ocean to ocean a distance of forty-seven miles, and to build it several large mountains had to be torn down in the center of the isthmus in order to lower the canal elevation. Millions of tons of earth were carted away to make way for the famous Culebra Cut. Gatun Lake, covering 150 square miles in the interior of the isthmus and eighty-five feet above the sea, had to be built, followed by the building of the Gatun Dam to control the Chagres River. Then came the construction of the great concrete lock on the biggest scale ever attempted. Throughout the seven years of work, until the canal was opened for navigation in 1914, General Goethals directed the job as engineer and administrator. His intimate knowledge of every detail is still talked about in army circles.

After the completion of the canal offers carrying handsome financial inducements began to pour in, but he turned them all down to stay at the Canal Zone as its first civil governor. Two years later he was retired at his own request and returned to the United States where he served as chairman of the board designated to report on the Adamson eight-hour law for railroad employees. In 1917 he was appointed state engineer of New Jersey, but after the United States entered the World War he resigned that post to accept the appointment as manager of the Emergency Fleet Corporation. He was later appointed acting quartermaster-general, U.S.A., and finally was made assistant chief of staff and director of purchase, storage, and traffic. He received the Distinguished Service Medal in 1918, and was also decorated by the French government with the Legion of Honor, Order of Commander, for his war service. In 1919 he resumed his profession of consulting engineer.

For many years he was associated with the Port of New York Authority and had much to do with the plans for the Holland Vehicular Tunnel and the bridge now under construction from New York to Fort Lee, New Jersey.

General Goethals received many honors from scientific and educational institutions. In 1917 he was made an honorary member of The American Society of Mechanical Engineers.

In accordance with his request he was buried in the military cemetery at West Point.

John Joseph Carty Receives John Fritz Medal

For Pioneer Achievement in Telephone Engineering and in the Development of Scientific Research in the Telephone Art

JOHN JOSEPH CARTY, Vice-President of the American Telephone and Telegraph Co., was presented with the John Fritz Medal in the Auditorium of the Engineering Societies Building on Wednesday evening, April 15, "for pioneer achievement in telephone engineering and in the development of scientific research in the telephone art."

Announcement of the award was made by J. V. W. Reynders, Chairman of the Board of Award and Past-President, American Institute of Mining and Metallurgical Engineers.

Bancroft Gherardi, President of the American Institute of Electrical Engineers, and Vice-President and Chief Engineer, American Telephone and Telegraph Company, delivered an address in which he reviewed the achievements of General Carty, following which the medal was presented by Robert Ridgeway, chairman of the board which made the award and Past-President, American Society of Civil Engineers.

General Carty responded in an address in which he pictured the engineer's function in societal evolution. He said in part:

COL. JOHN J. CARTY

Already, the applications of science to human affairs have far outrun the ability of man to use them wisely. The engineer has provided agencies of incalculable value in time of peace, but they are also endowed with prodigious powers of destruction which can be loosed in time of war. Unless we solve the problem encountered in man himself, the outlook is dark indeed, and it may even be questioned whether our civilization will endure.

Human behavior presents the most important and the most formidable problem of all the ages. Its solution can be achieved only by profound and prolonged researches, which shall bring upon every phase of the subject all of the resources of science.

While, in such a consideration as this, it would be folly to ignore the claims of religion and philosophy, it would be a grave error to conclude that, in order to avoid disaster, we must restrict progress in the application of science to material things. On the contrary, we must accelerate progress in all the sciences, for the knowledge thus gained will be required in preparing the individual man to function as a sane and peaceful unit in the ultimate social organism.

Scientific research in our universities and elsewhere, conducted solely for the increase of knowledge, should receive more adequate financial support, so that it may be prosecuted with ever-increasing vigor. If this is done, I believe that in the fullness of time, by further scientific discoveries, the physical development of man will be improved, that many diseases will be entirely eliminated, and that immunity to the others will be achieved, and that feeble-bodiedness and feeble-mindedness will disappear. Thus will be removed some of the greatest barriers to social progress.

In the great plan of evolution, the part assigned to the engineer calls for the highest exercise of his creative faculties, for he is to direct the evolution of man's extra-corporeal powers, providing him with more numerous and still more powerful additions to his feeble bodily equipment.

The ideals of the engineer will not be realized until man has achieved his destiny in that social organism which is foreshadowed "with its million-minded knowledge and power, to which no barrier will be insurmountable, no gulf impassable, and no task too great."

General Carty was born at Cambridge, Mass., April 14, 1861, and in 1879 he entered the service of the Bell Company in Boston. In 1887 he removed to New York to take charge of the cable department of the Western Electric Company in the East, directing all important cable-laying projects in eastern cities.

A study of the disturbances to which telephone lines are subject led General Carty in 1889 to present a paper entitled, "A New View of Telephone Transmission," in which he demonstrated the importance of electrostatic induction as a factor in producing cross-talk. This was followed in 1891 by a paper on "Inductive Disturbance in Telephone Circuits," describing for the first time the precise manner in which twisting or transposing telephone lines rendered them free from inductive disturbances.

General Carty became chief engineer of what is now known as the New York Telephone Company in 1889. He converted the company's switchboard and cable plant from the grounded to the metallic-circuit system and installed the wires underground. He also designed a telephone and signaling system by means of which twenty stations could be connected to one line, thus making possible an extraordinary extension of party lines in rural districts.

In 1907, General Carty became chief engineer of the American Telephone and Telegraph Company. He consolidated the laboratories into the great research institution now known as the Bell Telephone Laboratories and developed long-distance telephony, opening the New York-San Francisco service January 25, 1915 and establishing the first telephonic communication between American and Europe later in the same year.

As major in the Signal Reserve Corps, Carty was called to active service at the entrance of our country into the World War. He was responsible for maintaining trans-atlantic communication. He was made a Colonel in 1918 and a Brigadier General in the Reserve Corps in 1921. On return from France, General Carty reentered the service of the American Telephone and Telegraph Company as Vice-President, which office he now fills.

General Carty is a Past-President of the American Institute of

Electrical Engineers, an honorary member of the Franklin Institute, and Brigadier-General, U. S. Army Reserve Corps. He is a member of the National Academy of Sciences, the National Research Council, the American Academy of Arts and Sciences, and the American Philosophical Society. He has received the Distinguished Service Medal, United States of America; Cross of the Legion of Honor, France; Order of the Rising Sun, Japan; and Order of the Sacred Treasure, Japan; and the following medals: Franklin Medal of the Franklin Institute, Edward Longstreth Medal of the Franklin Institute, Edison Medal of the American Institute of Electrical Engineers. Stevens Institute of Technology and New York University have conferred upon General Carty the degree of Doctor of Engineering; University of Chicago, Bowdoin College, Tufts College, Yale University, and Princeton University the degree of Doctor of Science; and McGill University and University of Pennsylvania that of Doctor of Laws.

The conferring of the John Fritz Medal was a part of the activities of the Winter Convention of the American Institute of Electrical Engineers. On the same evening the Edison Medal was presented to Dr. William D. Coolidge "for his contributions to the incandescent electric lighting and the X-rays." Dr. M. I. Pupin made the presentation address, and the medal was presented by Bancroft Gherardi.

Book Reviews and Library Notes

THE Library is a cooperative activity of the A.S.C.E., the A.I.M.E., the A.S.M.E. and the A.I.E.E. It is administered by the United Engineering Society as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West 39th St., New York, N. Y. In order to place its resources at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references on engineering subjects, copies of translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

Business Management as a Profession

Business Management as a Profession. Edited by Henry C. Metcalf, Ph.D., Director, Bureau of Personnel Administration, New York City. A. W. Shaw Company, Chicago and New York, 1927. Cloth, 6 × 9 in., 377 pp., selected reading list, and index.

Reviewed by Joseph W. Roe[1]

THIS book is based on a series of lectures given in the Bureau of Personnel Administration, and is an effort to analyze the fundamentals of business administration and its development into a professional status.

The subject is approached from a number of angles. Of the thirteen contributors one is a manufacturer, one an industrial engineer, three are authors and lecturers on social subjects, one the director of the Taylor Society, one a personnel executive, and the remaining authors are teachers of economics, management, social science, and philosophy.

The first chapter, by Henry S. Dennison, gives four tests for professional status—the use of trained intelligence, an organized body of knowledge, a service motive, and established ethical standards. He traces the evolution of some of the older professions with respect to these standards, and points out some of the difficulties which business meets in connection with them.

The other authors concur with these standards as a basis for judging professional status. Coming at the subject from different points of view, they agree that judged by these standards business as a whole is not now a profession, but that more or less consciously it is tending toward them. The various analyses are worth while and helpful.

The ownership of business is steadily spreading, through the wider distribution of stock ownership, until now there are corporations which have more stockholders than employees. Because of this there is developing a body of executives whose authority rests on high administrative capacity rather than predominant ownership. This group is constantly growing, its training and its vision are broadening, and it is developing a composite responsibility to owners, employees, and the public, all of which is building up professional standards. Business itself is growing away from the pronounced individualism of the past century. Trade associations are developing collective action and recognizing and enforcing standards of business practice, first as between competitors and, more slowly, in dealings with the public. The various authors point out that forces are at work within business itself which are slowly developing the organized knowledge and ethical standards which are the basis of a true profession.

Business makes wide use of two of the older professions, law and engineering. The latter of these, through the industrial engineers, has reacted profoundly during the past generation on the technique of business organization and methods. Engineers, particularly mechanical engineers, who work largely within business organizations, will find much that is illuminating in this book. Possibly this is the more true because only one of the authors is an engineer and the book therefore brings out aspects and tendencies which an engineer might easily ignore.

[1] Professor of Industrial Engineering, New York University, New York City. Mem. A.S.M.E.

Books Received in the Library

American Men of Science; a Biographical Directory. Edited by J. McKeen Cattell and Jaques Cattell. Fourth edition. Science Press, New York, 1927. Cloth, 6 × 10 in., 1132 pp., $10.

Gives brief biographies of about 13,500 men who are engaged in scientific research in America, or who have contributed to the advancement of science by teaching or writing or by work in related fields, such as the applied sciences. A useful guide to the scientific workers of the country.

A.S.T.M. Standards, issued triennially. 1927; Part 1, Metals; Part 2, Non-metallic Materials. American Society for Testing

Materials. Philadelphia, 1927. Cloth, 6 × 9 in., 2 vols., illus., diagrams, tables, $14; half-leather, $17; volumes sold separately; cloth, $7.50; half-leather, $9.

This edition is one-half larger than that of 1924, the date of the last triennial revision, and contains a large number of new standards. There are now 147 standards relating to metals and 206 to non-metals. The standards include specifications, methods of test, definitions, and practices. A wise variety of commercial products of importance is covered, including materials for machinery, building and electrical equipment, road materials, fuels, lubricants and oils, preservative coatings, etc.

Auditing, Theory and Practice. By Robert H. Montgomery. Fourth edition. Ronald Press Co., New York, 1927. Cloth, 6 × 9 in., 859 pp., $6.

A comprehensive treatise, setting forth the principles underlying the practice of auditing, and outlining the work that must be done in an audit.

Der Bildsame Zustand der Werkstoffe. By A. Nádai. Julius Springer, Berlin, 1927. Paper, 7 × 10 in., 171 pp., illus., diagrams, 15 r.m.

Dr. Nádai describes the behavior of structural materials in the plastic state, in the light of his own researches at Göttingen, as well as those of other investigators. He brings together the information at present available for developing laws upon which the behavior of metals under stress may be predicted, and on the phenomena attending the plastic flow of solids.

Die Hebezeuge, 1; Entwurf von Winden und Kranen. By G. Tafel. Walter de Gruyter & Co., Berlin and Leipzig. Cloth, 4 × 6 in., 184 pp., illus., diagrams, 1.50 r.m.

A brief textbook on the design of cranes and hoists. Covers the principal types and methods of calculation, with an explanation of the advantages of each. The book is intended for builders and for purchasers of hoisting apparatus.

James Watt and the Steam Engine. By H. W. Dickinson and Rhys Jenkins. Clarendon Press, Oxford; Oxford University Press, New York, 1927. Cloth, 9 × 11 in., 415 pp., illus., portrait, $21.

This handsome volume, one of the results of the commemoration of the centenary of Watt's death, at Birmingham in 1919, will be valued by every student of the steam engine and of invention. It is the definitive work upon the labors of Watt, based upon first-hand study of the documents by two men with unusual qualifications for the task.

The book is divided into two parts, dealing respectively with the man and with his work upon the steam engine. The biographical section is comparatively brief. It gives salient facts about Watt's life, correcting some erroneous views that have been held until now. The second, and larger, section discusses critically the origin of his invention, the steps by which it was reduced to a practical form, and the development of the steam engine under his direction. The book is elaborately illustrated with portraits, and with photographs from the original Boulton and Watt drawings. A critical bibliography is included.

Manual of Industrial Safety. By Sidney J. Williams. A. W. Shaw Co., Chicago and New York, 1927. Cloth, 6 × 9 in., 197 pp., $2.50.

On the basis of his twenty years of experience with the Wisconsin Industrial Commission and the National Safety Council, the author has prepared this exposition of the essentials of safety work as a handbook for safety engineers and managers. It discusses the works safety organization, the training of employees, safety equipment, hazards, fire prevention, health, accidents and related topics, giving sufficient information to lead to the sources of complete descriptions of methods and practice.

Die Maschinenelemente, vol. 1. By Felix Rötscher. Julius Springer, Berlin, 1927. Bound, 8 × 11 in., 600 pp., illus., diagrams, 41 r.m.

An unusually comprehensive work on machine elements, intended both as a textbook and as a reference work for the designer. The first section gives a general review of the important formulas and principles of the strength of the materials; the second deals with the properties of the various materials. Section three discusses the general principles governing the form of machine elements. Succeeding sections treat of various elements in more or less detail. A useful list of references is included.

Throughout the discussion the author calls attention not only to the calculation of the various elements but also, the effects of methods of manufacture and of working conditions upon their form.

Mechanical Appliances, Mechanical Movements and Novelties of Construction. By Gardner D. Hiscox. Sixth edition. Norman W. Henley Publishing Co., New York, 1927. Cloth, 6 × 9 in., 412 pp., illus., $4.

This edition of this well-known collection of devices and machines has been enlarged by the addition of various new devices. The book is actually a simple dictionary of machines and appliances for various purposes, illustrated by numerous line sketches.

Mechanics Applied to Engineering. By John Goodman. Ninth edition. Longmans, Green & Co., New York, 1926–27. Two volumes. Cloth, 5 × 7$^1/_4$ in., diagrams, vol. 1, $4.80; vol. 2, $5.40.

Covers more subjects than is customary in American books on applied mechanics. Includes theoretical mechanics, the theory of framed structures, hydraulics and hydraulic motors, and the dynamics of steam engines. The book is designed to assist the student to apply his theoretical knowledge to practical problems. Straightforward, simple methods are used, which do not demand great mathematical skill. This edition has been enlarged by the addition of a second volume containing a large number of fully worked-out problems.

Modern Aircraft. By Victor W. Pagé. Norman W. Henley Publishing Co., New York, 1927. Cloth, 7 × 10 in., 855 pp., illus., diagrams, $5.

A general comprehensive manual of a descriptive nature. Covers the theory, construction, and operation of aircraft of all kinds in considerable detail. The book is well up to date and will interest those who wish to understand modern developments in construction and use.

Oil Tankers. By Robert W. Morrell. Simmons-Boardman Publishing Co., New York, 1927. Cloth, 5 × 8 in., 284 pp., diagrams, $3.

A discussion of the requirements and peculiarities of tank vessels. The book treats such topics as propelling machinery, structural design and construction, fire prevention, repairs, cargo oil piping, and operation. A chapter on oil-tank barges is included.

Psychological Foundations of Management. Edited by Henry C. Metcalf. A. W. Shaw Co., Chicago and New York, 1927. Cloth, 6 × 9 in., 309 pp., $6.

A collection of papers, by various authors, which point out some of the contributions to business management that have been made by industrial psychology, and define the difficulties of psychological research in the industrial field.

SCHIESS- UND SPRENGSTOFFE. By Ph. Naoum. Theodor Steinkopff, Dresden and Leipzig, 1927. Paper, 6 × 9 in., 199 pp., illus., 12.50 r.m.; bound, 14 r.m.

A monograph upon the manufacture of modern explosives in which developments during and since the World War are systematically presented, with ample references to the original publications.

STANDARDS AND SPECIFICATIONS IN THE WOOD-USING INDUSTRIES. By U. S. Bureau of Standards. (Miscellaneous publication, no. 79.) Washington, D. C., Government Printing Office, 1927. Cloth, 8 × 11 in., 349 pp., $1.50.

This volume represents the first attempt by the Department of Commerce to publish the substance of the standards and specifications in the woodworking industries which have been formulated by technical societies, trade associations, and other recognized authorities. An attempt has been made to include, directly or by adequate reference, the substance of all such standards and specifications covering timber, partly manufactured wood, lumber for building and factory use, wooden articles, furniture, paper, books and other printed matter, containers, electrical insulating paper, and pulleys. This material is classified thoroughly and conveniently. The book quickly shows what has been done, and also what has not been done, toward standardization in this field.

STEAM TURBINES. By Edwin F. Church. McGraw-Hill Book Co., New York, 1928. Cloth, 6 × 9 in., 273 pp., illus., diagrams, tables, $3.

The majority of the existing books on this subject are too exhaustive for classroom use, according to this author. He therefore has prepared this new textbook to fill the need for a short, but thorough, course to follow and apply the study of thermodynamics in engineering colleges.

STEEL AND ITS HEAT TREATMENT. By D. K. Bullens. Third edition. John Wiley & Sons, New York, 1927. Cloth, 6 × 9 in., 564 pp., illus., charts, tables, $5.

This edition presents marked differences from the second. The arrangement has been changed, and the matter now is grouped in three sections which treat respectively of the underlying metallurgical principles, the methods of developing the required engineering properties of the various steels, and the methods and equipment in use for heat treatment. New chapters have been added upon spheroidizing, molybdenum steels, tungsten steels, uranium, zirconium, cerium steels, chromium steels and on steel castings. Much new matter has been added.

TABLES ANNUELLES DE CONSTANTES ET DONNÉES NUMÉRIQUES. Vol. 6, Part 1. By International permanent Commission on Constants. Gauthier-Villars & Co., Paris; McGraw-Hill Book Co., New York, 1927. Cloth, 9 × 11 in., 679 pp., price of vol. 6, parts 1 and 2, $30; (Part 2, ready in March).

The first of two parts in which will be collected the numerical data and constants which were published during 1923 and 1924 in scientific and technical periodicals. The series of which it forms a part is very valuable to scientific workers, for it makes available, without exhaustive search, all the existing measurements of the properties of materials.

TEXTILE COLOUR MIXING. By David Paterson. D. Van Nostrand Co., New York, 1927. Cloth, 6 × 9 in., 130 pp., illus., plates, diagrams, $4.50.

A simple, practical treatise on the theory of color and its application in producing dyes for textiles. The book has been brought up to date by the substitution of modern dyes for those used before the war. In its new form it will be useful to dyers and colorists generally.

THERMODYNAMICS APPLIED TO ENGINEERING. By Arthur F. Macconochie. Longmans, Green & Co., New York and London, 1927. Cloth, 6 × 9 in., 260 pp., illus., diagrams, charts, $4.50.

Aims to present the principles in the simplest fashion and to illustrate these conceptions by reference to the best British and American practice in the major fields of their application.

Section one presents the theory of general thermodynamics. Section two treats the thermodynamics of the boiler, the steam engine (including the uniflow engine) and the steam turbine. Section three discusses internal-combustion engines, the gas turbine, and mechanical refrigeration.

THERMODYNAMISCHE GRUNDLAGEN DER KOLBEN- UND TURBO-KOMPRESSOREN. By Adolf Hinz. Second edition. Julius Springer, Berlin, 1927. Bound, 9 × 12 in., 68 pp., diagrams, charts, bound, 25 r.m.

These charts give quick, reliable answers to the complicated calculations that arise in designing compressors, and give the designer and testing engineers the bases for calculations about sizes and relationships in convenient graphic form.

THOMAS' REGISTER OF AMERICAN MANUFACTURERS. 1927–28. Thomas Publishing Co., New York, 1927. Cloth, 9 × 12 in., various paging, $15.

This directory of manufacturers and dealers covers practically every article made or sold in America, giving the names and addresses of the manufacturers and an indication of the size of each plant. Lists of representative banks, commercial organizations, trade papers, trade associations, and trade names are included. The book is directly valuable to purchasing and sales departments, while indirectly it is a source of much useful information on business.

VALUATION, DEPRECIATION AND THE RATE-BASE. By Carl Ewald Grunsky. Second edition. John Wiley & Sons, New York, 1927. Cloth, 6 × 9 in., 500 pp., tables, $5.

Dr. Grunsky has revised and extended his analysis of the valuation problem in this new edition. New chapters on The Standard of Value, on Some Elements Deserving Special Consideration When Rates Are to Be Fixed, and on A Few Recent Court Decisions have been added, and the tables have been increased in number and made more accurate.

VORLESUNGEN ÜBER DIFFERENTIAL-UND INTEGRALRECHNUNG, vol. 1; Funktionen einer Veränderlichen. By R. Courant. Julius Springer, Berlin, 1927. Cloth, 6 × 9 in., 410 pp., 18.60 r.m.

A textbook on the calculus, intended as an introduction to the subject for students in universities and engineering colleges. The chief points of novelty are the absence of any separation of differential and integral calculus, and the constant effort to call attention to their practical uses. This volume treats of functions with one variable; a second will complete the work.

ZÄHIGKEITSMESSUNGEN AN FLÜSSIGKEITEN UND UNTERSUCHUNGEN VON VISKOSIMETERN. By S. Erk. V.D.I. Verlag, Berlin, 1927. (Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, heft 288.) Paper, 8 × 11 in., 54 pp., diagrams, tables, 6 r.m.; V.D.I. members, 5.40 r.m.

The purpose of these investigations was the construction of a viscosimeter with an absolute scale, for basic measurements, and the examination of viscosimeters in practical use. A standard viscosimeter was constructed, with which the viscosity of aniline and various oils was measured at various temperatures. With this standard the exactitude and fields of usefulness of the Engler viscosimeter and other commercial types were then investigated and a formula derived for the conversion of measurements with them into absolute measurements.